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How Expert Pilots Think

Cognitive Processes in Expert Decision Making

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Final Report

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16. Abstract This report is the second in the investigation of the role of expert cognitive processes in Aeronautical Decision Making (ADM). The first report defined the differences between expert and novice decision makers and correlated the development of expert pilot cognitive processes with training and experience. This volume continues the research into the understanding of how pilots think by examining human information processing and expert problem solving characteristics. From this analysis: the mental attributes critical to developing expert decision making are explained, and three basic limits on decision making are identified. These are attention span, short term memory and long term memory.

Next, the analysis examines the development of Expert Decision Making (EDM) from the comparison of how novices and experts perceive, store, organize and use their knowledge. This analysis shows that high levels of competence result from the interaction between knowledge organization and processing abilities. Experts are found to possess the abilities of rapid access to, and efficient utilization of a highly organized body of conceptual and procedural knowledge. That is, an elaborately structured set of associated concepts, procedures and events -- based upon many years of study, training and experience in a aviation. The use of this knowledge base is described in terms of the characteristics of EDM related to perception, attention, memory, creativity and superior situational awareness.

Since the speed and accuracy of expert cognitive processes make them take on the characteristics of insight or intuition, the role of intuition in decision making is the next analytical part of the investigation. Intuition is defined and the properties of intuition relevant to EDM delineated.

Finally, the report concludes by presenting alternative EDM training opportunities. These include: training to enhance memory, computer based training tools, and promising methods for testing pilots which will also provide training and the opportunity to learn the cognitive skills of experts without spending all of the learning time in actual flight.

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PREFACE

In recent years, experienced pilots and crews have adequately responded to multiple failures for which there were no specified procedures, no previous simulator training and certainly no past experience. Explosive decompressions caused by cargo door failures, total loss of triply redundant hydraulic systems and fuselage failures were all situations which, within all reasonable statistical criteria, the aircraft manufacturers, the airlines, the regulatory agencies and the insurance companies could not conceive. Yet, these pilots and crews responded quickly, adapted their trained procedures to the task demands of the crises and either in whole or in part "saved the day".

During this same time period, first generation Aeronautical Decision Making (ADM) training was developed by joint efforts of the FAA, industry and academe. The ADM training, in some cases combined with Crew Resource Management training, has been shown to significantly reduce the percentage of accidents attributable to "human error". However, this initial type of ADM training, a serial, checklist evaluation of alternative decisions, has not been accepted by all pilots and is not readily applied in "knowledge lean", time-pressured multiple failures. Consequently, in 1990 the FAA initiated an effort to analyze and understand the more complex decision making and problem solving capabilities of the high time, experienced, "expert" pilot.

This is the second report in the effort to define the differences between novice and expert pilot decision making. The first report, "Introduction to Cognitive Processes of Expert Pilots" report number DOT/FAA/RD-92/12, reviewed accident scenarios and correlated the characteristics of these pilot's decisions with the characteristics of experts in other fields. It also analyzed the development of a pilot's knowledge and type of information processing with training and experience to show that many characteristics of Expert Decision Making (EDM) were enhanced as pilots accumulate flight time. The current report is an attempt to explore whether or not the development of EDM can be expedited by study and training in addition to the basic requirement for actual flight experience.

ACKNOWLEDGEMENTS

HOW EXPERT PILOTS THINK
Cognitive Processes in Expert Decision Making

Table of Contents

EXECUTIVE SUMMARY

The speed and accuracy of problem solving using memory is the fundamental process that accounts for differences between expert and novice pilot thinking capabilities. Sensing, organizing and using information requires the resources of short term and long term memory systems. Both types of memory are critically impacted by the quantity and structure of the available information. Since a pilot's stored information includes aeronautical knowledge (facts), procedural knowledge (ATC, aircraft and systems), training, attitudes, emotions and general skills, as well as experience, it is reasonable to expect that at least some portion of the expert thinking capabilities can be learned without relying solely on knowledge gained through actual flight experience. One goal of this research is to identify the expert capabilities that could be learned in a training environment.

Expert decision making is characterized by the speed and accuracy with which information can be retrieved and applied to new situations. The type of knowledge available, how it is represented (stored) in memory, how pilots tie it together and how they recall (apply) it are central to the understanding of cognition in general and how expert pilots think in particular.

This study first describes four basic steps that pilots use when thinking about a situation or solving a problem. Then, the performance of these steps is related to the basic human information processing systems used for problem solving and decision making. Finally, the unique elements of those systems which are used most efficiently by experts are described. This background provides the knowledge and understanding needed to begin development of expert pilot decision making training materials which is the second goal of this analysis. A brief overview of the contents and findings of this study is presented in this section.

COGNITIVE SOARING
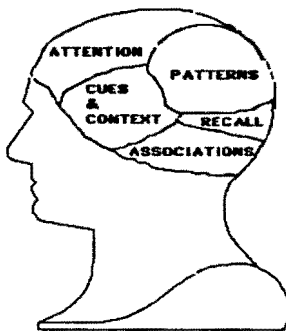
The focus of this analysis is on the PREPARATION and EXECUTION aspects of how expert pilots think since these two areas offer the greatest potential for improved training. For this analysis, the PREPARATION factor was limited to the cognitive aspects of Sensing and Organizing information. The EXECUTION factor was similarly limited to the cognitive aspects of Analyzing and Responding to the needs of the situation. Thus, the term Cognitive SOARing was coined to recognize the special level of expertise required to respond to previously inexperienced or abnormal situations and achieve the highest level of "adaptive" expert decision making. This nomenclature is also

beneficial to establishing the ultimate goal for Expert Decision Making (EDM) training, that is, adaptive expertise. However, any additional training in the mental characteristics and thinking processes described for cognitive SOARing will be responsive to the needs of the industry for advanced Aeronautical Decision Making (ADM) training which generated this research.

Sensing is the first preparation step involved in decision making. The basic characteristic of sensory memory that is important for pilots to be aware of is that a lot of information is "sensed" or received, but only a small amount is "attended to". Dedicated time spent focusing on individual cues and responding is time taken away from situation monitoring or passive situation assessment. Attention training can, therefore, provide the first part of a program designed to lessen the reliance on experience as the only means of attaining expert performance.

Organizing involves filtering, prioritizing and structuring sensed information. During this step, short term and long term memory resources are used to identify the most important information and develop an understanding of the situation. Short term memory and long term memory should not be thought of as different places pilots "put" facts or procedures. Rather, the differences in these two memory systems are based upon the "operational readiness" of the knowledge at any given time.

SHORT TERM MEMORY provides active, usable chunks of information in a state of readiness to be used. The precise content, organization and usability of each chunk is tied directly to exposure and practice. Therefore, pilot training and especially decision making training could benefit by re-examining the criticality of information chunking and training novice pilots earlier in the necessary short term memory skills.

LONG TERM MEMORY provides stored information including factual, procedural, experiential and emotional knowledge. Pilots have stored this knowledge in related patterns or schema and must reactivate it based upon the specific situation. Reactivation can be initiated by the cues (mental or physical), the context of a situation (standard procedure or emergency) and the pilot's abilities to make associations between current and previous patterns.

Analyzing (or information processing and evaluation) is the third critical step in pilot thinking. This step relies on the type of knowledge stored and how it can be retrieved. Expert pilots have developed superior long term memory organizational capabilities which facilitate RECOGNITION and RECALL. Experts use schema, pattern recognition, associative reasoning, elaborations and inferences to interpret the cues and context of a new situation based upon their related knowledge.

Responding is the most critical step of the Expert Decision Making (EDM) process. This step requires that the pilot take some action to alter or control the situation and

then monitor the effectiveness of that action. Responding involves the use of conceptual and procedural knowledge. Since aviation training is highly procedural both in developing flying skills (psychomotor) and in problem solving for normal and emergency situations, pilot's are provided the foundation for more sophisticated problem solving using production rules. PRODUCTION RULES consist of conceptual knowledge combined with general problem solving procedures (i.e., rules-of-thumb, working backward from a goal, etc.) to create new, problem specific procedures. The ability to develop problem specific production rules marks the early beginnings of how expert pilots think.

EXPERT DECISION MAKING
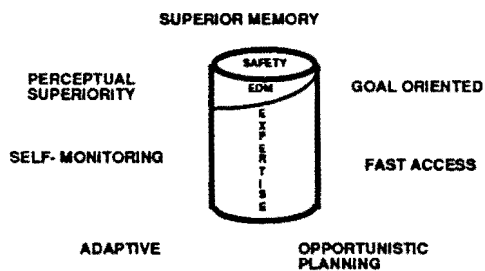
SUPERIOR MEMORY

PERCEPTUAL
SUPERIORITY

SAFETY
EDM

GOAL ORIENTED

SELF-MONITORING

FAST ACCESS

ADAPTIVE

OPPORTUNISTIC
PLANNING

As experience is gained the pilot begins to develop associative problem solving capabilities for enhanced decision making. As a result of experience, additional flight training and possibly a knowledge of ADM principles, the pilot develops a capacity for more dynamic thinking. Expert pilots can create new production rules and patterns in the vein of "opportunistic planning" based upon unique, previously unencountered problem characteristics. This capability to creatively respond to unique problems, novel task demands and chaotic situations identifies the highest level of EDM. At this level, the pilot has become an "adaptive" expert. The coordinated use of cues and context with stored schema (i.e., perceptual superiority) is believed to be a "major mechanism" used by experts to infer unobserved or unknown elements of a problem in knowledge lean or chaotic situations (Anderson 1985).

The expert pilot's perception of the whole situation involves mental representations that include physical, cognitive and internal effects which are used to both store and retrieve knowledge. Long familiarization in a specific field of knowledge transforms the experts mental representations into an accessible form of global knowledge. When applied to new problems or working situations the expert decision making capabilities occur so fast that they appear to take on the characteristics of instantaneous insight or intuition.

Operationally, INTUITION is critically important to EDM. The most meaningful definition of intuition from a training viewpoint is: "knowledge based on experiences and acquired through sensory contact" (Bastic, 1982). In this context, intuition can be viewed as an inferential process similar to ordinary perceptions. That is, intuition does not advance in careful, well-planned steps. It tends to involve responding to situations based seemingly on an implicit perception of the whole problem. As with other procedural knowledge, the pilot arrives at an answer and acts on it with little or no awareness of the process by which it was reached. This knowledge cannot be verbalized, but is activated by the cues and context of the

situation. Nevertheless, intuition is a highly rational skill and one that is sometimes necessary for pilots to use. Intuition is simply an extension of the logical problem solving process and an integral part of the "autonomous" stage of how pilots think. This stage requires extensive knowledge of the subject matter and basic principles in aeronautics and extensive experience in aviation. It is the fast access to large meaningful patterns of knowledge that "appears" intuitive to the observer

| RESULTS |

The primary focus of this analysis was on the capabilities and limits of the pilots sensory, short and long term memory systems since *memory is the fundamental process that accounts for differences in expert and novice pilot thinking capabilities* . Enhanced memory training to develop EDM in pilots is discussed in Sections 3.4 and 5.2. Secondly, the pilots Problem Solving abilities were related to type of knowledge, its organization and the process differences between novices and experts. The purpose of this discussion was to expand the understanding of how the SOARing processes were accomplished at the cognitive level and to specifically identify factors which could offer opportunities for enhanced training. These opportunities are discussed in Sections 4.1 and 5.4.

MENTAL ATTRIBUTE	INFORMATION PROCESSING SYSTEM
1. ATTENTION	SENSORY MEMORY
2. PERCEPTION	SENSORY MEMORY
3. CHUNKING	SHORT TERM MEMORY
4. SCHEMA	LONG TERM MEMORY
5. PATTERN RECOGNITION	LONG TERM MEMORY
6. CUES & CONTEXT	LONG TERM MEMORY
7. RECALL	LONG TERM MEMORY
8. ASSOCIATIONS	LONG TERM MEMORY
9. ELABORATIONS	LONG TERM MEMORY
10. INFERENCES	LONG TERM MEMORY
11. PROCEDURAL KNOWLEDGE	PROCESSOR
12. PRODUCTION RULES	PROCESSOR

Cognitive SOARing Attributes: In total, the 12 mental attributes listed on the left were identified as offering potential for developing future Expert Decision Making (EDM) training methods and materials. Other fields offer existing training programs for enhancing these mental attributes. These can be used as resources to expedite the development of EDM training programs for pilots. These are addressed and their adaptation explored in Section 5.2 and App. D.

Expert Decision Making Attributes: There are seven basic characteristics of Expert Decision Making which are extremely relevant to the desire to develop EDM training materials for pilots. These distinguishing characteristics have been identified in many fields of expertise, but they have particular importance in the current analysis of how pilots use their knowledge, training and experience to overcome the adversities associated with everyday flight, i.e., how pilots think. They are summarized for ease of reference as follows:

1. Superior Short Term and Long Term Memory	Experts' recall seems to exceed the limits of Short Term Memory. However, it is the autonomous information processing of many of their skills which frees-up greater storage. Elaborations, associations and inferences expedite Long Term recall as well.
2. Goal Oriented	The knowledge of experts is highly procedural and goal oriented. Concepts are bound to procedures for their applications and to conditions (contexts) under which these procedures are useful.
3. Fast Access	Experts can solve problems quickly and accurately for three reasons. They are faster at the skill based tasks. The faster skill performance frees-up working memory for processing other aspects of the problem. They can arrive at a solution without conducting extensive search of memory.
4. Opportunistic Planning	Experts develop the capability to revise production rules and to simultaneously access multiple possible interpretations of a situation. The development of this capability is influenced by task demands and experience.
5. Adaptive	There are both routine and adaptive experts. Either type is outstanding in terms of speed, accuracy and automaticity of their decision making. Adaptive experts possess the additional ability to creatively respond and develop solutions to knowledge lean or ambiguous situations.
6. Self-Monitoring	The greater knowledge bases and different knowledge representations of experts allow more time to predict problem difficulty on the basis of underlying principles and more time to monitor accurately how they should allocate their time for solving problems.
7. Perceptual Superiority	Experts have the ability to perceive large meaningful patterns due to the organization of their knowledge base. This organization is based on experience and training. The pattern recognition and recall occurs so rapidly that it takes on the characteristics of instantaneous insight or intuition.
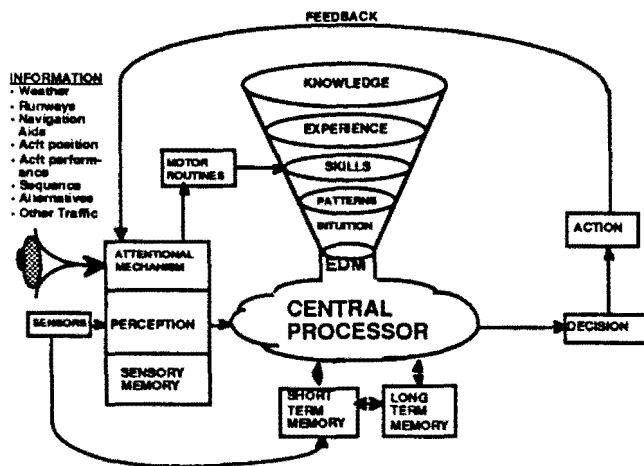
In summary, we have discussed the importance of the cues and context of the environment or the stimuli which "trigger" EDM or adaptive problem solving behavior. The importance of attentional resources, perception and motor skills in "aiding and abetting" EDM have been identified. The roles of short term and long term memory, including chunking and schema, have also been shown as critical to the pilot's strategic mobility and intuition.

Finally and most importantly from a training perspective, the foundation of the pilot knowledge and its organization have been identified as critical. These areas, attention, perception, memory, type of knowledge and its organization could be used as the crystal about which EDM training programs, materials, tools and methods can grow.

CONCLUSIONS AND RECOMMENDATIONS

Expert pilots need to know how to use the full range of their "thinking" capabilities depending on the cues, context, familiarity and difficulty of the situation. Research in many fields has shown that at least some of the expert decision making skills can be acquired through practice and training. The ultimate purpose of this research is to suggest a starting point for developing EDM training for pilots. The following conclusions and recommendations are tailored to that purpose.

CONCLUSION 1: Enhanced memory and problem solving training are required to expedite development of Expert Decision Making (EDM) in novice pilots.

Recommendation -- Aviation problem solving and pilot memory training courses should be developed. Three non-aviation cognitive training programs which offer potential insight for new EDM training paradigms were reviewed in Section 5.2. These and other programs which have documented improvements in attention, memory and problem solving should be explored and adapted to prototype EDM courseware.

CONCLUSION 2: The reliance of EDM on knowledge based on experiences and sensory stimuli make the selection of training media extremely critical.

Recommendation -- The development of a knowledge based CBT or IVT expert training device should be initiated. The fields of Activity Based Learning (ABL), Computer Based Training (CBT) and Interactive Video Training (IVT) offer near term, cost effective alternatives which are attractive to both air lines and general aviation pilots. Two example CBT systems were discussed in Section 5.2.

CONCLUSION 3: Experience since 1986 with ADM training in both civil and military U. S. operations has shown that **decision making can be taught and this training reduces the number of human error accidents.**

Recommendation -- A second generation ADM or EDM training manual should be developed in response to industry's request for additional material and to continue the safety improvements generated by this training. Much of the material needed for this manual has already been created during Phases I and II of this project. Reformatting the EDM research into a training manual could be accomplished in a timely, cost effective manner.

CONCLUSION 4: An FAA EDM training program should be developed and tested. Courseware, an instructor's syllabus, student manuals and self test materials are required.

Recommendation -- The aviation EDM training/testing conducted at Massey University in New Zealand (Section 5.4) since 1990 should be the starting point for an FAA EDM course for pilots. The Intuitive Decision Making testing from non-aviation fields (Section 5.4) should be reviewed for possible relevance or enhancements of the Massey program.

CONCLUSION 5: A written self-assessment test would be the most expeditious and cost effective method of raising the awareness of aviator EDM characteristics and initiating EDM training.

Recommendation -- Continue development of the Cognitive SOARing self-assessment test initiated in Section 5.4 for rating individual pilot EDM capabilities.

SOAR SELF-TEST SCALES

1. SENSING AND INTERPRETING CUES AND CONTEXT	S	ACTIVE —— PASSIVE
2. FILTERING AND ORGANIZING INFORMATION	O	SERIAL —— PARALLEL
3. ANALYZING AND PROCESSING INFORMATION	A	CONCEPTUAL —— PROCEDURAL
4. DECISION MAKING, PROBLEM SOLVING AND RESPONDING	R	COGNITIVE —— AUTONOMOUS

CONCLUSION 6: Selecting realistic EDM scenarios with critical events and performing a cognitive task analysis of novice vs. expert decision making for these events is a basic requirement for future EDM training development.

Recommendation -- The design of EDM training assessment methods should be initiated in parallel with training materials, training tools and courseware development. A methodology and implications of developing EDM scenarios are presented in Appendix F. This type of methodology is required for Activity Based Learning (Recommendation 2), a second generation training manual (Recommendation 3) and self-assessment written testing (Recommendation 5).

Due to the number of topics, the complex interrelationships, and the desire to make this report as easy to read as possible, the following diagram is provided as a guide or road map. The boxes indicate the type and sequence of the primary subject matter discussed. As you proceed from section-to-section, refer back to this road map to retain the perspective of where you are in the discussion and how the material relates to the overall EDM process.

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                        ┌──────────────────────────────────┐
                        │  AERONAUTICAL DECISION MAKING     │
                        │  & PILOT EXPERTISE EXAMPLES       │
                        └──────────────────────────────────┘
BACKGROUND ─────────────────────────────┼──────────────────────────────────

              ┌──────────────┐      ┌──────────────┐
              │ INFORMATION  │      │ PROBLEM      │
              │ PROCESSING   │      │ SOLVING      │
              └──────────────┘      └──────────────┘

THINKING ACTIVITIES ────────────────────┼──────────────────────────────────

        ┌──────────┐  ┌──────────────┐  ┌──────────────┐
        │ MEMORY   │  │ EXPERT       │  │ INTUITIVE    │
        │          │  │ DECISION     │  │ DECISION     │
        │          │  │ MAKING (EDM) │  │ MAKING (IDM) │
        └──────────┘  └──────────────┘  └──────────────┘

  ┌──────────────┐   ┌──────────────┐   ┌──────────────┐
  │ EDM          │   │ CURRENT      │   │ IDM          │
  │ CHARACTERISTICS│ │ TRAINING IMPACTS│ │ CHARACTERISTICS│
  └──────────────┘   └──────────────┘   └──────────────┘

PILOTING & AIRMANSHIP ──────────────────────────────────────────────────

  ┌──────────────┐   ┌──────────────┐   ┌──────────────┐
  │ TRAINING     │   │ TRAINING     │   │ TRAINING     │
  │ OPPORTUNITIES│   │ TOOLS        │   │ METHODS      │
  └──────────────┘   └──────────────┘   └──────────────┘

TRAINING APPROACHES ────────────────────────────────────────────────────
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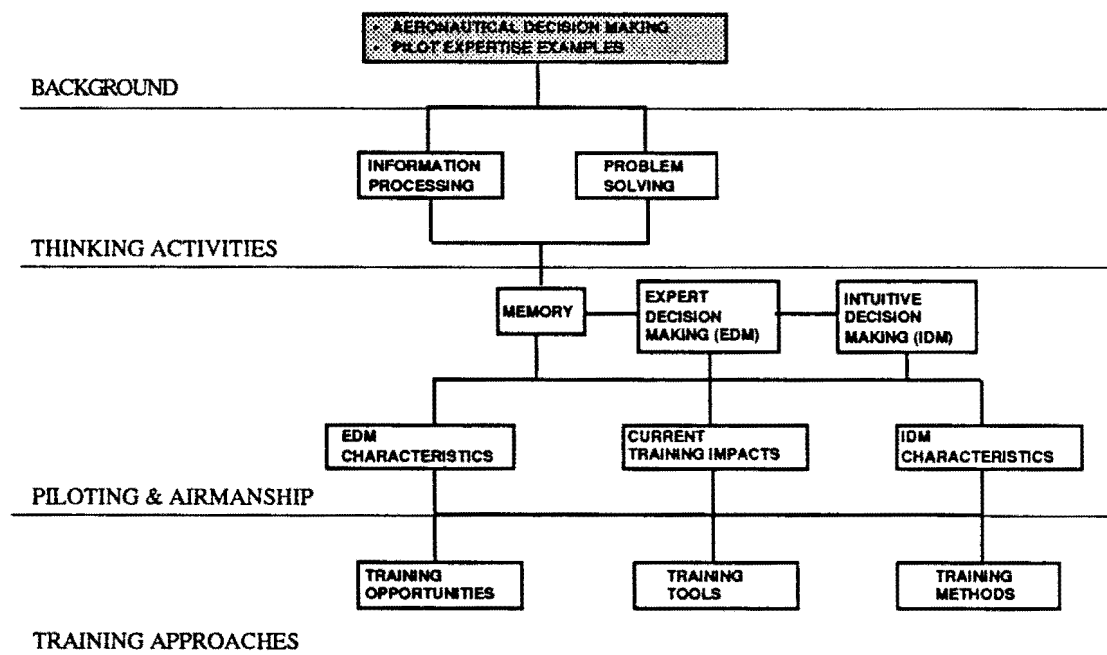
HOW EXPERT PILOTS THINK
Cognitive Processes in Expert Decision Making

1.0   PURPOSE

Both operators and researchers have recognized decision making -- *the ability of a pilot to respond to cues from the environment, evaluate the situation, come to conclusions and act on those conclusions* -- as possibly the only reason for keeping a human on the flight deck in the future (Green & Muir, 1991). This research is an attempt to articulate steps for development of training materials and formulation of training tools responsive to the need for early development of these skills.

The ability to identify a problem while it develops, often before it has fully developed, select an optimal solution and then implement it at the right time is the distinguishing trait of an expert pilot. This ability to anticipate trouble and respond in a timely manner, with confidence, involves both natural and learned behavior employing perception, memory, problem solving and decision making skills. Expert's use forward thinking and start solving problems from an intuitive perception of the situation. These perceptions are based upon the context and cues available from the situation as well as experience and training. The latest research has shown that these abilities can be learned through tailored training (Agor, 1986, Firestein & McCowan, 1988 and Hogarth 1989). This report provides the background of primary decision making characteristics of experts in order to establish a common foundation of knowledge for addressing how pilots can be trained expert decision making.

The objectives of this study are:

• To identify the expert decision making characteristics that could be learned in a training environment, and

• To provide the knowledge and understanding needed to begin development of expert pilot decision making training materials and tools.

This will require examining the mental processes used by expert pilots and the characteristic thinking abilities they have developed to meet the demands of their flying tasks. Specifically, the processes and abilities needed by pilots to perform fast, accurate decision making in normal situations, trained emergency situations and abnormal emergencies will be analyzed.

2.0 BACKGROUND: ADM Training History, Successes and Limitations

The work described in this report was initiated in October of 1990 with a Phase I study which investigated the differences between novice and expert pilot decision

making from an information processing perspective (Adams & Ericsson, 1992). The Phase I report correlated the development of expert decision making with pilot training and experience, and reviewed accident scenarios which exemplified those processes. The need for this introductory study evolved from 10 years of Aeronautical Decision Making (ADM) research (1975-1985) sponsored primarily by the Federal Aviation Administration and performed by industry and academia. This research lead to the publication of a series of 10 training manuals and reports on ADM (1986-1988). Topics included the range of airplane pilot ADM training manuals from student/private candidates to multicrew resource management, as well as, reports devoted to helicopter pilots, flight instructors and EMS.

SUCCESSES

	HE REDUCTIONS
• 10 EXPERIMENTAL VALIDATIONS	8-46%
• WORLD CIVIL HELICOPTERS (B206)	
– ALL H.E. ACCIDENTS	36%
– WX RELATED ACCIDENTS	72%
• U.S. CIVIL HELICOPTERS	
– B206 ALL H.E. ACCIDENTS	48%
– PH ALL ACCIDENTS	54%
• U.S. MILITARY	
– AF TRANSPORT CREWS	51%
– NAVY HELICOPTERS	20%
– NAVY AIRPLANES (A6 & EA6)	81%

Extensive experimental validations and empirical testing in both civil and military operational environments have documented that accident rate reductions of about 50% can be seen when comparing pilot groups with and without decision making training. Although it is difficult to accurately assess the impact of these manuals throughout aviation, significant reductions in Human Error (HE) accidents have been demonstrated in the specific aviation applications shown at the left (Diehl, 1991).

This basic research defined judgment as: the ability to stay on top of and control the flight situation, and the motivation to assure safety through timely decisions. ADM identified hazardous attitudes in flight operations and provided pilots with a self-assessment test by which to judge their own abilities. The method stressed situational awareness and a structured approach to decision making to enhance the pilot's application of conventional flight training, knowledge, skill and experience. The methods taught to accomplish good decision making stressed serial, deductive reasoning in a checklist form using the DECIDE model (Detect, Estimate, Choose, Identify, Do, Evaluate). This method is useful to novices, but not necessarily representative of the more advanced decision making abilities used by expert pilots.

BASIC

AERONAUTICAL DECISION MAKING (ADM)

* Defined Judgment
* Identified hazardous attitudes
* Developed self-test
* Stressed situational awareness
* Utilized the "Decide" Model

The specific shortcomings of this approach included: the great difficulty in carrying out the linear analysis under conditions of time pressure, the difficulty in applying it to problems with incomplete information or ambiguous data, and that it was not representative of documented differences between novice and expert decision makers in other fields (Chi & Glaser, 1988).

2

All of these shortcomings lead the industry to come back to the FAA with a request for additional training material for use in training of novice pilots and for use in both initial and recurrency training with more experienced pilots.

3.0   EXPERT DECISION MAKING (EDM)

Developing EDM training involves unraveling the relationships between cognition (how pilot's think in operational situations) and training. Conventional pilot training has been based upon a foundation of skill based, rule based and knowledge based tasks. That is, pilots are taught conceptual knowledge; flying procedures; and, basic pilot skills while leaving the development of decision making to the realm of experience. The novice pilot, therefore, is expected to learn: aerodynamics, airplane performance, electrical and hydraulic systems, Federal Aviation Regulations, etc. He is then trained in aircraft control and operation for both normal and emergency situations. This training includes procedures development for preflight, takeoff, cruise, approach and landing phases of flight. Through this training, the novice develops and improves his basic psychomotor abilities and hones his flying skills.

At this stage, decision making is only taught informally through training session debriefs, hangar flying, analyses of other pilots experiences and the limited flight experience gained in preparation for an airman certification test. After successfully passing the test, the novice pilot is expected to cautiously begin developing good decision making and judgment skills as he gains experience. Because of the emphasis of aviation on procedure oriented training both in developing flying skills and in decision making skills, training lays the foundation for the development of more sophisticated decision making as experience is gained.

3.1 EXPERTISE IN ACTION: The Type C Pilot

Common characteristics of expert decision making have been observed in the fields of mathematics, physics, medicine, music, sports and aviation (Ericsson, 1991). In fact, individuals with expert thinking ability have been identified as a new personality type. First the classic Type A and B personalities were identified, individuals who respond dramatically differently to stressful situations. Then the Type T or Thrill-seeking personalities, those who seek out the "edge-of-the-envelope" and enjoy the challenge of overcoming dangerous situations was recognized. Now psychologists have identified the Type C personality style as Chaos changing individuals who are expert problem solvers. *Type C individuals have a tolerance for ambiguity, can see solutions in unfamiliar and information lean environments and develop action plans even in time compressed situations* (Buffington, 1989).

The most dramatic examples of how Type C pilots and crews apply their expert thinking skills have occurred in several airline accidents listed on the following page. The catastrophic engine failure and subsequent total failure of the triply

AERONAUTICAL DECISION MAKING

EXPERTISE IN ACTION

DATE	LOCATION	AIRLINE	AIRCRAFT	TYPE
7-19-89	SIOUX CITY	UAL	DC-10-10	Eng. fail
2-24-89	HONOLULU	UAL	B-747-122	Cargo door
4-28-88	MAUI	ALOHA	B-737-200	Fuselage
7-23-83	GIMLI	Air Canada	B-767	Fuel Strv.
6-02-83	CINCINNATI	Air Canada	DC-9-32	Cabin Fire

redundant flight control system of a United Air Lines DC-10 (Flight 232), the failure of a cargo door and explosive decompression of another United B-747 (Flight 811), and the fuselage separation of an Aloha Air Lines B-737 (Flight 243) are three prime examples of abnormal situations in which Type C problem solving abilities were used to overcome chaotic situations for which there were no specified procedures, no previous simulator training and certainly no past experience. The event histories of these accidents were analyzed during Phase I of this project to provide specific examples of how expert pilots think (Adams & Ericsson, 1992). For ease of reference, the expert pilot decision making process demonstrated by Captain Al Haynes of United Flight 232 will be reviewed here.

In a speech on January 26, 1991, Captain Haynes reported that the transition from a normal, uneventful takeoff and climb to 37,000 feet to a "nearly uncontrollable"

EXPERTISE IN ACTION

Cpt. Haynes and crew faced with a multiple emergency had to "improvise." There was no training provided for impossible occurences.
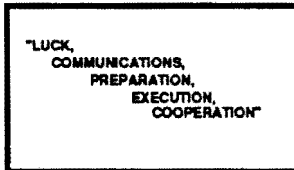
EVENT	CHARACTERISTIC
• Catastrophic Engine Failure	• Recall
• Total Hydraulic Failure	• Reasoning
• Loss of flight Controls	• Reasoning
• Aerodynamic Instability	• Reasoning
• Regaining Some controlability	• Basic Airmanship
• Adding Crew Member	• Reasoning/CRM
• High Speed Landing	• Reasoning
• Non-Trained Event	• Self Assurance

aircraft occurred in about 15 seconds. His first response was reverting to basic airmanship skills (i.e., figuring out how to fly the airplane). His ingrained training in crew resource management was evident by: his immediate decision to use the abilities of a check airman to operate the throttles and maintain heading with differential thrust; his utilization of the second officer for damage assessment; his concern for the passengers and coordination with the flight attendant; and, his professional communication with the air traffic controller.

Captain Haynes' behavior clearly show the expert pilots ability to assimilate data and impressions quickly, formulate a solution and carry it out while maintaining mental composure under extreme time pressures. However, even with complete utilization of his expertise and all available personnel, pitch oscillations (60 second phugoids) and roll reversals (from 4-28 degrees of bank) were as stable an approach as the aircraft could make. Regardless, Captain Haynes reported that he was always "confident of getting the aircraft on the ground". This expert thinking -- knowing what to do and when to do it -- and the taming of a chaotic situation is the real mark of the Type C decision maker.

4

After the accident, Captain Haynes stated that the five factors listed on the left were instrumental in his ability to land the aircraft and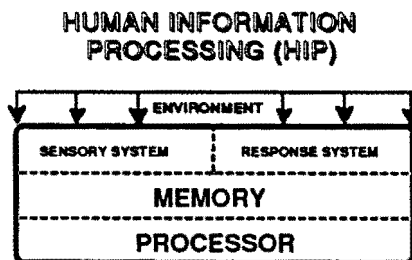 save as many lives as he did. The focus of this report is on the PREPARATION and EXECUTION aspects of how expert pilots think. Since the way these tasks are performed in practice strongly affects how they will be performed during an emergency, these areas offer the greatest potential for improved training. The factors and processes involved in these two critical decision making areas include: Sensing, Organizing, Analyzing and Responding to the cues and contexts of the situation. The Type C behavior documented by Captain Haynes, his crew and the crews of the other "aviation saves" is referred to herein as Cognitive SOARing to recognize the special level of expertise required for abnormal emergencies. This nomenclature is also beneficial to establishing an ultimate goal for Expert Decision Making (EDM) training. However, any additional training in the mental characteristics and thinking processes described for Cognitive Soaring will be responsive to the needs of the industry which generated this research project.

EXPERTISE IN ACTION

What are the factors involved in the decisions that successful pilots execute?

> "LUCK,
> COMMUNICATIONS,
> PREPARATION,
> EXECUTION,
> COOPERATION"

3.2 COGNITIVE SOARING: Sensing, Organizing, Analyzing and Responding

The study of cognition over the past 40 years has identified the importance of four systems used in thinking or "information processing". These systems are illustrated in the Human Information Processing (HIP) diagram. Basically, the human information processing system includes: the sensory systems (visual, auditory, seat-of-the-pants, etc.), the memory systems (long term, short term and sensory memory), the processor and the response systems (motor events, communications, etc.). These four systems incorporate the basic characteristic concepts which contribute to the individual's cognitive SOARing capabilities. Equally important to the expert pilot's thinking are the types of knowledge and types of processing available for use with these systems. These factors as well as the characteristic concepts will provide the focus for the following description. A more detailed examination of important memory and problem solving characteristics is provided in Appendix A.

HUMAN INFORMATION PROCESSING (HIP)

ENVIRONMENT	
SENSORY SYSTEM	RESPONSE SYSTEM
MEMORY	
PROCESSOR	

Sensing is the first preparation step involved in decision making. Pilots vary in the way they perceive (recognize and sort) information from the cues and context of a situation. SENSORY MEMORY provides enough retention to allow a reasoned response to each situation. The basic characteristic of sensory memory that is important for pilots to be aware of is that a lot of information is "sensed" or received, but only a small amount is "attended to". Dedicated time spent focusing

on individual cues and responding is time taken away from situation monitoring or passive situation assessment.

Since the amount of time pilots spend actively attending to sensory inputs vs. passively monitoring the cues and context of a situation varies directly with knowledge, training, experience and currency, each of these elements impact the pilots ability to respond in a timely fashion to specific situations. Consequently, ATTENTION is one of the differentiators which can be used to identify experts vs. novices. Attention training can, therefore, provide the first part of a program designed to lessen the reliance on experience as the only means of attaining expert performance.

Organizing involves filtering, prioritizing and structuring sensed information. During this step, short term and long term memory resources are used to identify the most important information and develop an understanding of the situation or problem. This understanding is formulated into a group of related facts, data, results and procedures, that is, a pattern which characterizes the current situation and can be used to retrieve related information from short and long term memory. Although the novice and expert pilot have equal capability for cognitive processing, novices typically use lots of search and processing time in a less focused and more general manner. The outstanding performance of experts is derived from how their knowldege is structured in short and long term memory for retrieval, pattern recognition and inference.

Short term memory and long term memory should not be thought of as different places pilots "put" facts or procedures. Rather, the differences in these two memory systems are based upon the "operational readiness" of the knowledge at any given time. SHORT TERM MEMORY provides active, usable chunks of information in a state of readiness to be used. The precise content, organization and usability of each chunk is tied directly to exposure and pracitce. Therefore, pilot training and especially decision making training could benefit by re-examining the criticality of information chunking and train novice pilots earlier in the necessary short term memory skills.

LONG TERM MEMORY provides stored information including factual, procedural, experiential and emotional knowledge. Pilots have strored this knowledge in related groups or schema and must reactivate it based upon the specific situation. Reactivation can be initiated by the cues (mental or physical), the context of a situation (standard procedure or emergency) and the pilot's abilities to make associations between current and previous patterns. Long term memory, then, depends on the pilot's ability to respond to new demands for information through his abilities of recognition and recall.

Analyzing (or information processing and evaluation) is the third critical step in pilot thinking. This step relies on the type of knowledge stored and how it can be retrieved. Once again, expert pilots have developed superior long term memory

organizational capabilities which facilitate RECOGNITION and RECALL. Experts use schema, pattern recognition, associative reasoning, elaborations and inferences to interpret the cues and context of a new situation based upon their related knowledge. This expert capability manifests itself in the ability to intuitively respond to patterns without decomposing them into component features or problem elements. An example of these abilities would be the expert's ability to respond to loss of an engine on takeoff without consciously "thinking through" the engine out procedure. This understanding occurs effortlessly due to the experts knowledge structure.

The experts ability to fast access their schema (concepts or patterns) of aviation knowledge is expedited by the ASSOCIATIONS with cues and context of new situations which stimulate the recall process. Although the associations (or concept ELABORATIONS) are predominantly based upon experience today, training aimed at replicating this ability is not an unreasonable goal. In addition to the elaborations, the expert's ability to use INFERENCES to aid reconstruction of similar problems and solutions could also comprise part of this training.

HIP -- PROBLEM SOLVING
Goal oriented cognitive behavior.

CONCEPTUAL = "FACTS & THINGS"

PROCEDURAL = "COGNITIVE ACTIVITIES"

PROCESSOR — ALGORITHMS, HEURISTICS, PRODUCTION RULES

Responding is the most critical step of the Expert Decision Making (EDM) process. This step requires that the pilot take some action to alter or control the situation and then monitor the effectiveness of that action. Responding involves the use of conceptual and procedural knowledge. Since aviation training is highly procedural both in developing flying skills (psychomotor) and in problem solving for normal and emergency situations, pilot's are provided the foundation for more sophisticated problem solving using production rules. PRODUCTION RULES consist of conceptual knowledge combined with general problem solving procedures (i.e., heuristics, algorithms, working backward from a goal, etc.) to create new, problem specific procedures. How the application of problem specific production rules develops in pilots is summarized in Section 3.3. This ability marks the early begininnings of how expert pilots think. As these rules are used more and more often, and applied to many situations, they result in autonomous generation of specilized production rules which often use forward inferencing to progress from the initial problem toward a solution or goal.

3.3 PROBLEM SOLVING: Expert vs. Novice

Problem solving is defined as behavior that is task dependent and purposeful (goal oriented). Therefore, the following discussion is about how pilots use their knowledge, thinking skills and the cues or stimuli of a situation to develop problem solving approaches. These very often cannot be completely or adequately verbalized; for example, how to properly judge and consistently perform the landing flare could be broken down and described but the result would lose the essentials of

7

the "how-to". To begin to understand the problem solving process, it is necessary to examine some basic differences between how novices and experts approach problem solving.

Problem solving can be described in terms of situational awareness and decision making in aviation. A pilot is expected to do more than skillfully resolve emergencies when they occur. It is equally important to actively avoid situations that might lead to emergencies by sensing and identifying early signs of impending problems and taking corrective action before a critical situation develops. This responsibility requires vigilant monitoring of the environment and the situation relative to the planned sequence of events during a flight. Problem solving can be thought of as a search for ways to return to the desired plan or the setting of a new goal once a change or deviation from the desired plan is recognized.

This section is about the knowledge underlying novice and expert problem solving activities. It presents a major change of emphasis in the analysis of how pilots think. Up to this point, the analysis has been concerned with <u>how</u> knowledge about the environment or situation gets into the system (i.e., is sensed and perceived) and <u>how</u> it is stored (chunks and schema) in, and retrieved (recall and recognition) from, memory. This kind of knowledge is referred to as declarative knowledge or conceptual knowledge. **Conceptual knowledge** consists of knowledge that can be verbalized or knowledge about "facts and things". Problem solving uses this type of knowledge as a basic resource, but requires another type of knowledge, Procedural knowledge, to understand how sensed and perceived information is used in the thinking process.

Procedural knowledge is knowledge about actions or how to perform various cognitive activities. This is the type of knowledge you learn by "doing" such as stall recovery and crosswind landings. Problem solving with procedural knowledge is more of a stimuli-response (or learned association of facts, actions and results) with which certain conditions cause certain "learned" (through experience) results. All information processing, and therefore problem solving, involves procedural knowledge, i.e., tying conceptual knowledge, environmental inputs and situational memories together by association to confront new situations.

HIP -- PROBLEM SOLVING

PRODUCTION RULES :

DECLARITIVE KNOWLEDGE + GENERAL
PROBLEM SOLVING RULES (HUERESTICS) TO
CREATE NEW DOMAIN SPECIFIC PROCEDURES

Significant differences exist between the mental processing performed by novices and experts in how they approach problem solving. In order to understand these differences it is useful to define three types of thinking or cognitive processes: Algorithms, Heuristics, and Production Rules.

Algorithms are procedures guaranteed to result in the correct solution of a problem. Algorithms involve a systematic and thorough search of the conceptual and procedural knowledge base, an examination of every single possibility and evaluating alternative solutions until the problem is solved. For example, deciding

how to use all the fuel aboard in the proper sequence to insure no fuel starvation or out of balance condition during a max duration flight involves: knowledge of the aircraft's capacities, recent fuel consumption, wind velocity at various altitudes, etc. This decision requires extensive searching of stored knowledge; identifying, recalling and sorting of alternatives; and, selecting the correct alternative. This process involves forward and backward searching, setting of intermediate goals, recognizing similarities and differences, drawing analogies and evaluating all alternatives. This type of thinking or problem solving is very accurate, but extremely time consuming and often not practical in real time problem solving.

Heuristics are "rules of thumb" which offer a much more efficient and often the operationally useful solution of a problem, but not necessarily the correct solution in every case. In short, heuristics are approximate but useful problem solving techniques. In aviation, the 200 pound male passenger, the 50 foot FAA tree, the average fuel consumption used to check flight progress, and flight manual values for average cruise speed, best rate of climb, etc. are all heuristics.

Production rules consist of conceptual knowledge combined with general problem solving procedures to create new, problem specific procedures. Procedures in this sense include: flying, navigating and ATC as well as heuristic and reasoning procedures.

The current theory of problem solving is that a novice first solves problems by weak, domain general, heuristic methods (often working backwards from the goal); successful solutions (when repeated frequently) lead to the development of domain specific production rules and the beginnings of expertise; as these rules are used more and more often, and applied to many situations, they result in automatic generation of specialized production rules which often use forward inferencing to progress from the initial problem toward a solution or goal. Relative to the novice, the expert is able to reach the correct solution more quickly and efficiently.

As experience is gained the pilot begins to develop associative problem solving capabilities for enhanced decision making. As a result of experience, additional flight training and possibly a knowledge of ADM principles, the pilot develops a capacity for more dynamic thinking. Information is stored in terms of schema based upon experience and training. The pilot uses pattern recognition and dynamic interrelationships among objects, situations and results to associate, integrate and interpret related knowledge instead of the static, linear thinking of the novice. This level of problem solving is characterized by the early development of the capabilities of an expert decision maker in that certain large patterns are spontaneously recognized (such as the necessity of a go-around when an approach is too high and fast) rather than requiring a conscious search of conceptual knowledge and a checklist review of problem solving steps.

Since experts have extensive information stored as schema, this information can be used to alter procedures in real time (modify, delete or expand). Expert pilots can

create new production rules and patterns based upon unique, previously unencountered problem characteristics. This capability to creatively respond to unique problems, novel task demands and chaotic situations identifies the highest level of expert decision making (EDM). At this level the pilot has become an "adaptive" expert. Furthermore, the coordinated use of cues and context with stored schema is believed to be a "major mechanism" used by experts to infer unobserved or unknown elements of a problem in knowledge lean or chaotic situations (Anderson, 1985).

3.4 SOARing Summary

This section has presented a unique view of how pilots think based upon: Expertise in Action; Information Processing System characteristics; and, Problem Solving processes. The Captain of the UAL flight 232 (used as an example of successful decision making and problem solving in chaotic, multiple failures) expressed the opinion that PREPARATION AND EXECUTION were critical factors involved in his decision making and problem solving. For this analysis the PREPARATION factor was limited to the cognitive aspects of Sensing and Organizing information. The EXECUTION factor was similarly limited to the cognitive aspects of Analyzing and Responding to the needs of the situation.

This analysis of the mental aspects of preparation and execution lead to the coining of the term Cognitive SOARing for the "Taming of the Chaotic Situation" demonstrated in several of the recent air carrier accident "saves". This type of problem solving behavior has been recognized and identified in the psychology field as Type C behavior where solutions are developed under time pressured, ambiguous circumstances. Successful training of Type C problem solving behavior has been demonstrated in other fields (Buffington, 1989, Firestein & McCowan, 1988) as discussed in Appendix C. The transfer of this training to aviation offers potential enhanced decision making training for pilots and should be addressed in future research.

HUMAN INFORMATION PROCESSING (HIP)
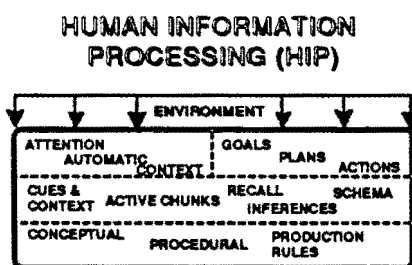
The analysis of how expert pilots think was then expanded by a specific review of the Human Information Processing (HIP) systems. The primary focus of this discussion was on the capabilities and limits of the pilots sensory, short and long term memory systems since *memory is the fundamental process that accounts for differences in expert and novice pilot thinking capabilities* . Enhanced memory training to develop EDM in pilots is also discussed in Appendix B. Finally, the pilots Problem Solving abilities were related to type of knowledge, its organization and the process differences between novices and experts. The purpose of this discussion was to expand the understanding of how the SOARing processes were accomplished at the cognitive level and to specifically identify factors which could offer opportunities for enhanced training.

10

MENTAL ATTRIBUTE	INFORMATION PROCESSING SYSTEM
1. ATTENTION	SENSORY MEMORY
2. PERCEPTION	SENSORY MEMORY
3. CHUNKING	SHORT TERM MEMORY
4. SCHEMA	LONG TERM MEMORY
5. PATTERN RECOGNITION	LONG TERM MEMORY
6. CUES & CONTEXT	LONG TERM MEMORY
7. RECALL	LONG TERM MEMORY
8. ASSOCIATIONS	LONG TERM MEMORY
9. ELABORATIONS	LONG TERM MEMORY
10. INFERENCES	LONG TERM MEMORY
11. PROCEDURAL KNOWLEDGE	PROCESSOR
12. PRODUCTION RULES	PROCESSOR

In total, 12 information processing attributes were identified as offering potential for developing future Expert Decision Making (EDM) training methods and materials. Other fields offer existing training programs for enhancing these mental attributes as illustrated in Section 5.2 and Appendix C. These can be used as resources to expedite the development of EDM training programs for pilots.

3.5 DEVELOPING EDM TRAINING: Initial Aspects

The historical approach to pilot training has focused on three basically different categories or levels of piloting tasks. These are: skill based psychomotor tasks, rule based perceptualmotor tasks and knowledge based tasks. The skill based tasks are those which have been learned and stored as psychomotor routines. These tasks can typically be performed without conscious thought. Actions such as moving the throttle or the control surfaces are examples since the initial conscious intent is translated into the desired actions automatically.

Rule based behaviors are those "procedures" which have been learned and practiced throughout early training in response to both normal and emergency flying tasks. These procedures consist of a set of discrete steps necessary to successful task completion. Performing a takeoff after engine failure at V_1 in an airliner, engine out procedures on a light twin airplane, and autorotation in a helicopter are typical of these rule based tasks.

EXPERT DECISION MAKING
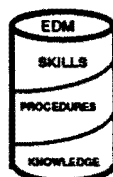
Knowledge based tasks are those for which no single, specific skill or procedure has been established. Knowledge based behavior is the essence of decision making or pilot thinking and will provide the basis for understanding the steps necessary to develop expert decision making (EDM) training programs. The way in which expert pilots evaluate information from the environment, use

memory and come to conclusions will be described in order to differentiate between what is currently trained and what is perceived as needed training to achieve the next breakthrough in the reduction of human error accidents.

These tasks require the information processing and problem solving abilities analyzed in detail in the previous section. The basic thrust of the following analysis will be: to examine differences between how novice and expert pilots use their knowledge bases; to define the distinguishing factors of expert decision makers; to analyze the relationship between current training and EDM characteristics; and finally, to describe the cognitive processing characteristics common to adaptive experts, Type C problem solvers and chaos changing pilots.

4.0 EDM AND INTUITIVE THINKING

The analysis of EDM has shown that, basically, experts structure information differently in memory and integrate new information rapidly. In expert pilots, these decision making skills have been demonstrated to provide keen, quick insight and almost a direct perception of the proper course of action. This insight results in decisional behavior based upon intuition. Aviation author Richard Collins has recognized patience, intuition, organization, composure, decisiveness and coordination as critical to safe flight (Collins, 1989). He describes the role of intuition in aviation as follows: "An intuitive pilot is less likely to be surprised, and avoiding surprises is a key to flying well".

4.1 EDM Characteristics

In actuality, the experienced pilot or expert decision maker sorts the available information into categories or "chunks" more meaningful to the goal of the current task, for example, continued safe flight. Essentially, *experienced pilots change a structured, deductive decision process into a cued recall task based upon the most significant chunks of information and make a decision based upon deductive reasoning supplemented by an inductive or inferential decision making style.*

AN EXAMPLE

The United Airlines flight 811, Boeing 747 accident, in particular, illustrates how experienced pilots rely on intuition. The pilot was faced with handling multiple emergencies that resulted from a 10 by 15 foot hole in the fuselage created by the failure of a cargo door. He was faced with the explosive decompression of the cabin, the failure of two engines on the same wing, and a malfunctioning oxygen system as he reached 22,000 feet. The normal response to a sudden de pressurization is to execute a power dive. But, in a critical decision, he opted to be cautious and descend at a much slower speed. He slowed the B747 to as close to stall speed as possible to keep the air rushing over the plane from further widening the hole or doing more damage to the wing. The trick was not to go too slow. Since the hole changed the aerodynamics of the plane, he really did not know the stall speed under these circumstances.

Upon reaching 4000 feet, he was faced with insufficient time to dump the remaining 300,000 pounds of fuel and flaps that could only be extended 10 degrees rather than the normal 20 degrees for a two engine landing. He decided to land as quickly as possible. This meant landing at 195 miles per hour vs. the normal 170 and landing about 36,000 pounds over Boeing's recommended maximum stress load of 564,000 pounds.

With fire trucks standing and ambulances standing by, the Captain made what some flight attendants later told investigators was one of the smoothest landings they had experienced. In this case, the pilot's skill and experience combined with keen intuition and improvisation to keep the plane from crashing. This example further illustrates the fast access to an expert knowledge base of aerodynamic principles, his adaptability and the autonomous use of basic flying skills in an unpredictable, abnormal situation.

12

Therefore, development of EDM is influenced by task demands encountered in the course of experience and training. Experts develop the capability for opportunistic planning which enables them to revise problem representations and to access multiple possible interpretations of a situation. These multiple patterns are quickly assessed and used to develop an "internal" visualization and then create a goal oriented scenario that can be played -- put in fine detail and in "slow-time" -- to a successful solution. In contrast, novices are less flexible and slower.

Experts build a mental representation of meaningful relationships in a situation. These relationships are more than the cognitive knowledge perceived by novices in the same situation. Long familiarization in a specific field of knowledge transforms the experts mental representations into large meaningful patterns which when applied to working situations provide the fast access characteristic of intuitive responding to a situation (Bastic, 1982).

Experts also possess self-monitoring or metacognitive abilities that are not present in less experienced decision makers (Glaser, 1987). Experts develop skilled self-regulatory processes that free working memory for higher level conscious processing. These capabilities include: planning ahead, efficiently monitoring one's time and attentional resources, and monitoring and editing one's efforts to solve a problem.

These observations lead to an interesting contradiction. Prior to the development of ADM training, it was widely held that good decision making could only be learned through experience. The 15 years of ADM work has contradicted this logic by showing that some aspects of good decisions can be trained. However, we have now realized that there is another, more subtle impact of experience on decision making in which the steps of the process are hidden in the perceptual and procedural portion of human information processing. Aviation decision making, especially in a situation (i.e., emergency) characterized by rapid, unexpected changes and crises requires an adept use of this inferential process which has been called intuition.

In summary, there are seven basic characteristics of Expert Decision Making which are extremely relevant to the desire to develop EDM training materials for pilots. These distinguishing characteristics have been identified in many fields of expertise, but they have particular importance in the current analysis of how pilots use their knowledge, training and experience to overcome the adversities associated with everyday flight, i.e., how pilots think. They are listed in the figure on the left and summarized for ease of reference as follows:

13

A. Superior Short Term and Long Term Memory

The material presented indicates that experts' recall seems to exceed the limits of Short Term Memory. Not larger than other humans', but autonomous information processing of many of their skills frees-up greater storage. Experts seem to excel in Long Term recall as well. Elaborations, associations and inferences expedite recall. Cues and context give recall the advantage over recognition.

B. Goal Oriented

The knowledge of experts is highly procedural and goal oriented. Concepts are bound to procedures for their applications and to conditions (contexts) under which these procedures are useful. This functional knowledge is strongly related to task demands and goals invaluable in problem solving.

C. Fast Access

Experts can solve problems quickly and accurately for three reasons. They are faster at the skill based tasks. The faster skill performance frees-up working memory for processing other aspects of the problem. They can arrive at a solution without conducting extensive search of memory.

D. Opportunistic Planning

Experts develop the capability to revise production rules and to simultaneously access multiple possible interpretations of a situation. The development of this capability is influenced by task demands and experience.
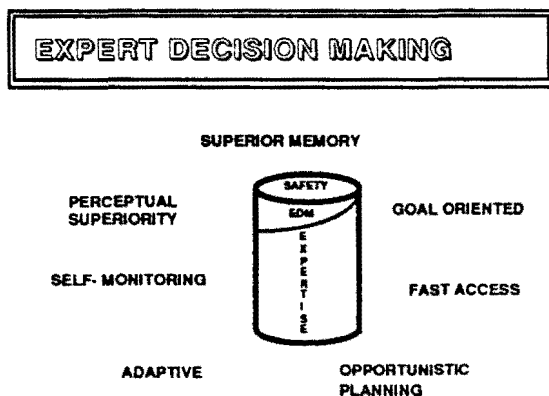
E. Adaptive

There are both routine and adaptive experts. Either type is outstanding in terms of speed, accuracy and automaticity of their decision making. Either type can construct mental models convenient for their tasks. While both are very confident in the execution of their solutions, routine experts have somewhat limited capabilities in dealing with new or ill structured problems. Adaptive experts possess the ability to creatively respond and develop solutions to ill structured or ambiguous new problems with some reasonable chance for a successful outcome.

F. Self-Monitoring

The greater knowledge bases and different knowledge representations of experts allow more time to predict problem difficulty on the basis of underlying principles and more time to monitor accurately how they should allocate their time for solving problems. This solution monitoring or self-regulatory capability are manifested by experts developing automaticity in performing basic operations, by their allocation of attention, and by their sensitivity to informational feedback.

G. Perceptual Superiority

Experts have the ability to perceive large meaningful patterns due to the organization of their knowledge base. This organization is based on long familiarization (experience and training) in a field. The pattern recognition and recall occurs so rapidly that it takes on the characteristics of instantaneous insight or intuition.

EXPERT DECISION MAKING

SUPERIOR MEMORY

PERCEPTUAL SUPERIORITY

SAFETY
EDM
EXPERTISE

GOAL ORIENTED

SELF-MONITORING

FAST ACCESS

ADAPTIVE

OPPORTUNISTIC PLANNING

This project was designed to search for enhanced cognitive training solutions in order to resolve the contradiction of current ADM training . The research described in previous sections has provided the foundation for those enhancements in memory training, problem solving training and expertise training. The characteristics documented for expertise has led to the exploration of the role of intuition in the way pilots respond to normal, emergency and sometimes novel (or chaotic) situations. The following analysis is intended to provide additional refinements to the

development of second generation ADM training materials and if possible lead to enhanced or Expert Decision Making training which can be learned without sole reliance on experience in an aircraft.

4.2 Intuition Characteristics

Intuition has been called "one of the most important faculties of man" (Lorenz, 1951). All of us have intuitive abilities. In various degrees they pervade everything we do. They range from the scientist's Eureka experiences to the day-to-day hunches and "feelings" which guide more common decisions. The literature (Fishbein, 1972) discusses two types of intuition:

a. Primary -   *basic instincts* constructed without any systematic process
                    (we are not addressing this type of intuition)
b. Secondary -   *academically learned* (or knowledge based) intuitions (e. g.,
                    lift/drag and power/pitch airmanship decisions

Operationally, the secondary type of intuition is critically important to EDM. The most meaningful definition of intuition (Bastic, 1982) for the purposes of this discussion is:

"Knowledge based on experiences and acquired through sensory contact".

In this context, intuition can be viewed as an inferential process similar to ordinary perceptions. That is, intuition does not advance in a linear set of steps. It tends to involve responding to situations based seemingly on an implicit perception of the whole problem. As with other procedural knowledge, the pilot arrives at an answer and acts on it but can have little or no awareness of the process by which he reached it. Furthermore, this knowledge cannot be verbalized beforehand as it is activated by the cues and context of the situation. Nevertheless, intuition is a rational skill and one that is sometimes necessary for pilots to use. Intuition is an extension of the logical problem solving process and one in which the steps of the process are hidden in the subconscious portion of the brain.

The basic characteristics of intuition are defined in Appendix B. These characteristics are listed on the following page with those properties most applicable to how expert pilots think indicated in **bold** type. These characteristics are provided as more definitive descriptors of intuition. They are not independent or necessarily observable. The apparent relationship between these characteristics of intuition and Expert Decision Making listed offers additional opportunities for EDM training material development.

15

The detailed analysis (Appendix A) of Expert Decision Making points out that intuition is an integral part of the "autonomous" stage of how pilots think. Intuition requires extensive knowledge of the subject matter and basic principles of aeronautics and extensive experience in aviation. It is the fast access to large

INTUITION PROPERTIES	EDM APPLICATION
1. QUICK, IMMEDIATE, APPEARANCE	
2. EMOTIONAL INVOLVEMENT	
3. PRECONSCIOUS PROCESS	AUTONOMOUS PROCESSING
4. NOT ANALYTICAL PROBLEM SOLVING, LOGIC OR ABSTRACT REASONING	
5. INFLUENCED BY EXPERIENCE	KNOWLEDGE ORGANIZATION & ELABORATION
6. EMOTIVE NOT TACTILE	
7. ASSOCIATED WITH CREATIVITY	ADAPTIVE EXPERT
8. ASSOCIATED WITH EGOCENTRICITY	
9. INTUITION NEED NOT BE CORRECT	
10. SUBJECTIVE CERTAINTY OF CORRECTNESS	PILOTS ARE SELF-ASSURED & OPTIMISTIC DECISION MAKERS
11. RECENTERING	
12. EMPATHY, KINESTHETIC OR OTHER	
13. INNATE, KNOWLEDGE OR ABILITY	
14. PREVERBAL CONCEPT	
15. GLOBAL KNOWLEDGE	LARGE MEANINGFUL PATTERNS
16. INCOMPLETE KNOWLEDGE	ILL-STRUCTURED, AMBIGUOUS AND KNOWLEDGE LEAN PROBLEM SOLVING
17. HYPNOGOGIC REVERIE	
18. SENSE OF RELATIONS	PATTERN RECOGNITION
19. DEPENDENCE ON ENVIRONMENT	CUES AND CONTEXT OF SITUATIONS OR DECISION TASK DEMANDS
20. TRANSFER AND TRANSPOSITION	

meaningful patterns of knowledge that "appears" intuitive to the observer. In actuality, the autonomous decision maker's ability to respond creatively to novel situations or ill-structured problems relies on his knowledge structure and experience. In fact, intuitive mental processes seem to be common whenever the situations become too complex for logical analysis. In this sense, intuition is a superior form of cognition.

5.0 EDM TRAINING DEVELOPMENT

Pilot decision making experience is currently developed over many years and thousands of hours of learning and exposure. As with other fields of expertise, the pilots decision making abilities continue to develop throughout his career and training as a function of practice. That is, his conceptual knowledge, procedural

knowledge and flying skills continue to expand and to provide more associations, elaborations, inferences and patterns with which problems can be solved. As pointed out in the literature (Chi, Glaser & Farr, 1988 and Ericsson, 1991), studies have been carried out in many other fields which illustrate the need for many years of full time experience and training to achieve the level of Expert. Third generation theories of expertise suggest that more than 10 years experience may be required to reach the level of Adaptive Expert (Holyoak, 1990).

Furthermore, it is a common observation in aviation as well as research on Expert Decision Making that in the course of acquiring expertise, plateaus in development are observed which apparently indicate shifts in understanding and the change from knowledge based processing to autonomous, procedurally dominant processing. This has led to the conclusion that although both novices and experts have similar capacities for processing, the outstanding performance of experts derives from their knowledge based on "experiences" (that is familiarity with contexts and cues) which facilitate situational awareness, the anticipation of risk and the task oriented decision making required to reduce or manage the risk.

Keeping in mind the importance of skill based, rule based and knowledge based training on the content and organization of a pilot's knowledge, this section correlates the more specific aspects of current pilot training with the characteristics identified for Expert Decision Making. The following table correlates experience based pilot decision making and problem solving characteristics with the (EDM) capabilities identified in Section 4.1.

CURRENT TRAINING ELEMENTS	EXPERT DECISION MAKING CHARACTERISTICS (NOTE: √ = PRIMARY RELATIONSHIP & 0 = SECONDARY)						
	SUPERIOR MEMORY	GOAL ORIENTED	FAST ACCESS	OPPORTU-NISTIC	ADAPTIVE	SELF-MON-ITORING	PERCEPTUAL SUPERIORITY
RELIES ON PRACTICE/REPETITION	√					0	√
CONTEXT (TASK DEMAND) BASED	√	√	0				0
SKILL BASED	√		√				
RULE (PROCEDURES) BASED		√	0				
AUTOMATIC		√	√		√		
KNOWLEDGE BASED	0		√				√
GOAL ORIENTED		√		√			
POSITIVE APPROACH & OPTIMISTIC		0		0	√		
SITUATION AWARENESS			0		√	√	√
AERONAUTICAL DECISION MAKING		0		√	0	√	
RISK MANAGEMENT		0		√		√	
JUDGMENT		0		√	√	0	√

The purpose of this table is twofold. First, it illustrates the important correlation between the factors involved in EDM and those which are currently trained. Second, it indicates that the Expert Decision Makers more complex characteristics: opportunistic planning, adaptivity, self-monitoring and perceptual superiority rely

17

on the cognitive characteristics or thinking capabilities of autonomous information processing. These were pointed out in Section 3.0 as creative problem solving (i.e., opportunistic planning and adaptivity), judgment and intuition or insight. The discussion which follows expands on these characteristics in order to complete the delineation of those areas which could comprise enhanced or expert pilot decision making training programs.

WHAT DO WE REMEMBER ?

- **10% OF WHAT WE READ**
- **20% OF WHAT WE HEAR**
- **30% OF WHAT WE SEE**
- **50% OF WHAT WE HEAR & SEE**
- **70% OF WHAT WE SAY**
- **90% OF WHAT WE SAY & DO**

REFERENCE: VERVALIN, C. H., 1991. MANAGEMENT AND THE
TECHNICAL PROFESSIONAL. GULF PUBLISHING

5.1 EDM Training Materials, Methods and Tools)

Now that we have reviewed the characteristics of how experts think and how these same processes apply to expert pilot decision making, we have discovered that the important problem solving activities become more-and-more automatic. In fact, the speed and accuracy become so dominant that the experts "intuitively respond" even as tension and problem complexities mount and go beyond the "practiced" emergencies. More importantly, by listing the gradual build-up of properties important to EDM:

-- attention, short term memory, long term memory
-- large meaningful patterns of knowledge, adaptivity, self-monitoring
-- influenced by experience, self-assured, dependent on environment

we have illustrated that expertise and intuition are not separate phenomena, but as noted by Nobel Laureate Herbert Simon "aspects of the same thing" (Benderly, 1989). Dr. Simon, professor of computer science at Carnegie Mellon University, is one of several researchers including Dr. Robert Glaser, psychology professor at the University of Pittsburgh, Dr. Robin Hogarth, Center for Decision Research at the University of Chicago, and their associates, who reject the idea that intuition is an inexplicable gift. These noted scientists explain that intuition is a predictable product of the way experts think. Even more importantly, their work suggests that intuition may be an ability that individuals can work toward and organizations (i.e. airlines, training schools, NTSB, FAA, etc.) can foster.

The principles of this research have been thoroughly described in the first four sections of this report. The next step, trying how to figure out methods to train EDM and maybe a little intuitive ability, will be addressed in the following pages. However, the physical limits of time and funding will not permit great detail or rigor in the methods outlined. The intent of this discussion is twofold: to introduce

the methods which are more fully described in Appendices C, D and E; and, to provide direction and focus for future research which appears to offer the next great improvement in reducing decision making errors.

ENHANCED TRAINING CONCEPTS

- NEW PARADIGMS FOR EXPERT DECISION MAKING
- CHAOTIC PROCESS MODELING AND NOVEL CUES
- APPLICATIONS OF ACTIVITY BASED LEARNING
- INTERACTIVE METHODS AND TOOLS

In striving to achieve this goal, it is necessary to depart from conventional aviation training in several respects. First, new paradigms for developing decision making training need to be considered without the limitations of current training and/or testing syllabi. The EDM paradigms need to break with the conventional, linear, checklist ADM training in order to make the necessary revolutionary strides in safety improvements. These should include the recent developments in modeling chaotic processes, i.e., processes that are non-linear and very sensitive to initial conditions. Second, several non-aviation fields need to be explored where applicable types of training either already exist or have been evaluated from a research perspective (see Appendix C examples). Third, decisions about the training media need to be considered (Appendix D.

The reliance of both expertise and intuition on "experience", the environmental stimuli, and the cues and context of the situation make this decision extremely relevant. The fields of Activity Based Learning and Interactive Computer or Video Based Training (CBT/VBT) devices offer near term cost effective alternatives which are attractive to both airline and general aviation pilots alike. In 1991, one of the major U. S. air carriers invested $4.5 million in interactive technology to train about 1000 pilots per day as well as software for training flight attendants, cargo-handlers and ticket agents (Todd, 1991). Yet, none of this training addressed the important areas of decision making training, the important elements of cognitive SOARing or problem solving expertise. Furthermore, this relatively mature, and inexpensive type of training is not available to the general aviation community except on a limited basis (See CEPET Section 5.3.A and Appendix D.1). The kinds of applications which are and are not suitable for CBT will be discussed when the available systems are reviewed.

5.2 Related Cognitive Training Methods

Three examples of existing non-aviation cognitive training program opportunities (programs which may offer some aviation applications and potential) are reviewed in Appendix C. These include:

• BRAIN GYM -- A program to improve memory, logic, attention and organizational ability. The month long course has reported the following results:

1. a 32.5% improvement in mental agility
2. a 47.3% improvement in visual/spatial memory
3. a 20.1% improvement in verbal memory

• TYPE C PROBLEM SOLVING -- This program has trained thousands of individuals in effective problem solving, i.e., identifying the right problem and implementing the right solution at the appropriate time. It involves a two phase, six step method employing a stepwise problem solving model that uses forward inferencing in the information processing solution.

• THOUGHT TRIALS -- A program to improve the decision related skills of association, retention and creative problem solving. The thought trial program is based upon the theory that creative thinking and problem solving involves the same principles as trial-and-error learning. By providing individuals with a very large number of associative problem solving paths, the thought trial process builds the individuals ability to provide foresight in new situations. Furthermore, the paths which lead to correct solutions are retained as strong connections since the overt behavior of "finding" a solution is accompanied by the feelings of accomplishment and discovery.

5.3 Existing EDM Tools

This section provides three examples of Expert Decision Making tools which can be used for either training decision making skills, evaluating cognitive performance or in one case as a screening tool to determine a priori if a student pilot has good decision making skills. These tools were selected due to their tailored development in the aviation human error reduction field. However, they are not intended to represent the recommended choices or even a prioritized list. Rather, they are to

- CEPET - INTERACTIVE COMPUTER OR VIDEO
  TRAINING DEVICE

- WOMBAT - WONDROUS ORIGINAL METHOD FOR
  BASIC AIRMANSHIP TRAINING

- CRM OR LOS - COGNITIVE EFFECTIVENESS
  MARKERS

represent the type of interactive tools which can expedite and enhance how pilot's think and solve problems.

Additional tools may be available of which the author is not aware. Also, the type of interactive and evaluative efforts discussed here are meant to be representative of the kind of cost effective, state-of-the-art technology that could bring EDM training to a much broader segment of the pilot population.

A. CEPET

The Cockpit Emergency Procedures Expert Trainer (CEPET) is a personal computer-based training program which contains expert pilot knowledge about cockpit emergency procedures and pilot decision making. CEPET was developed by Bell Helicopter Textron, and is currently available for four helicopter models: the Bell 206B3, 206L3, 212, and 412. The CEPET knowledge based software addresses good and bad decision making, attention, dual task loading, fatigue, emotion, overcompensation and risk taking.

The program has several modules dealing with flight planning, flight scenarios, situational awareness and stress management. Questions and answers are addressed interactively in the areas of helicopter systems, normal and emergency procedures, weather, Air Traffic Control and airspace. Some of the modules start a flight scenario with an initial set of cues. The student pilot or recurrent trainee identifies the problem and chooses an appropriate action. Other modules ask the pilots questions about some of the more serious emergencies that would call for premature landings. As the pilot responds to the various scenarios and questions with his aeronautical, systems or helicopter knowledge, the program helps in identifying the probable causes of the various emergencies and recommends appropriate actions. The pilot can practice his ability to recognize problems with only partial cues and choose the correct solutions. A more detailed description is provided in Appendix D.1

B. WOMBAT

The Wondrous Original Method for Basic Airmanship Testing (WOMBAT) is a pilot decision making evaluation and selection tool designed to screen pilots for the basic abilities or attributes credited to operationally effective pilots. In this sense, it

21

offers a potential development path for more sophisticated EDM training devices. WOMBAT was initially developed for the U. S. Air Force by Dr. Stanley Roscoe and his research team at ILLIANA Aviation Sciences based in Las Cruces, New Mexico.

WOMBAT is a microprocessor based system which integrates generic information processing algorithms with new pictorial codes and new decisional paradigms. In this way, scenarios are generated which require dynamic information sensing and processing with changing outputs and new opportunities for more decisions and problem solving. Pilot's earn or lose points at varying rates by the way in which they analyze the situation, infer the rules, invest attentional resources and capitalize on opportunities to score when serendipitous occasions are presented. A more detailed description is provided in Appendix D.2.

C. Cognitive Effectiveness Markers

A very different type of evaluation tool is currently being developed for multi-crew decision making and problem solving. In the air line environment, the 1990s have become a period of focusing on crew resource management (CRM). That is, a time when the true team resources are described not only in terms of the cockpit crew but include: the cabin crew, dispatch and maintenance personnel. This team performance has been recognized as a critical part of insuring safe and efficient flight.

Consequently, Dr. Robert Helmreich of the FAA/NASA/University of Texas Crew Performance Project has been developing a set of observable, evaluatable performance markers to accomplish this task (Butler, 1992). He calls them Behavioral Performance Markers. The emphasis in this assessment process includes the integration of cognitive, interpersonal and technical skills evaluation of the flightcrew's performance. The airlines, the FAA's ARD-200 and AFS-210 have all been involved in this developmental process (Lofaro, 1992). In fact, ATA Working Group quarterly meetings have been held for the past two years with the results that the Cognitive and Interpersonal markers have been included in the latest draft FAA Advisory Circular on CRM (Anon, AC 120-51a, 1992). Although this work is still maturing, it has had wide spread distribution. Several major air carriers feel that it is readily adaptable to extensive crew and single pilot cognitive effectiveness evaluations. Assessment of its usefulness is expected to take place primarily in the air line industry as outlined in the FAA's requirements for Advanced Qualification Programs.

5.4 Promising EDM Training Programs

Based on the research from Phase I and II of this project on Expert Decision Making, three promising EDM training/testing methods are suggested as applicable to future pilot training in decision making. These are:

- Metacognition Training (under evaluation using novice pilots at Massey University in New Zealand)
- Intuitive Decision Making Testing (evaluated intuitive decision making skills of over 3000 managers)
- Cognitive SOARingTesting and Training (developed as a part of this FAA project)

The first two methods have been empirically tested and offer encouraging examples of what can be done. The third method is a proposal for future EDM testing and training that could carry this FAA research into expert decision making forward to the verification and validation stage.

A. Metacognition Training

The School of Aviation at Massey University in New Zealand has been developing and evaluating training of ab initio pilots in the cognitive skills of experts since 1990 (Hunt, 1991). Their pilot training program assesses each incoming student pilot for their information processing styles. The **learning profile** derived from this assessment becomes the basis for working with students to develop their decision making, problem solving and metacognitive (self-monitoring) abilities. Specific emphasis is placed on self-monitoring and self-evaluation of the decision making process. This program is summarized here and reviewed in detail in Appendix E to illustrate what can be accomplished and what may be an interesting avenue for rther research and development by the Federal Aviation Administration.

e training program at Massey University recognizes the importance of strategic formation processing in pilot performance of both normal and emergency tasks. addition to the usual focus of ab initio training on manipulative skills and aditional content such as navigation, aircraft systems management, etc. their rogram provides training in the broader context of information processing. This raining is based upon the recognition that the more common causes of pilot error lave an underlying information processing function and that if the trainee pilots can improve the efficiency and effectiveness of their "thinking", and thus improve their monitoring and evaluative functions, then, their overall performance as pilot-in-command will improve.

Due to the dilemma of developing a course for the average student while trying to teach expert decision making, it was necessary to develop a compromise between individual attention and group learning. Therefore, the course begins with an overview of information processing and the factors which can influence effective learning. The basic course syllabus provides the students with the appropriate

knowledge and procedures to interpret and understand their own "thinking" or decision making processes.

These include the Approach to Learning, the Self Concept and Metacognition. Very early in the course the pilots are introduced to time-pressured and dynamic decision situations. They are required to identify actions, set priorities and apportion their time to specific tasks. They are encouraged to continually review and evaluate their decisions.

The following rating factors are used in the evaluation of the student pilot performance by the instructor. **First,** they are rated on their ability to analyze objectives and evaluate the content of the task or situation. **Second,** they are evaluated on the appropriate application of conceptual knowledge (facts) or procedural knowledge (rules) used to address the situation. **Third,** they are evaluated on the remembering and retention phase. For each objective identifying the required processing level helps the student to choose the appropriate cognitive strategies for learning.

Massey's first information processing course has been completed but a final assessment of the successes and failures has not been reported at this time. However, preliminary data presented at the 1991 Sixth International Symposium on Aviation Psychology showed some promising indications. These are:

"At the start of the course students were able to identify between 0-5 strategies for remembering type learning tasks, and 0-3 for deep learning tasks. Approximately 45% of the strategies they suggested were inappropriate to the nature of the task. After six months into the program, information from at least 30 study sessions per student showed that they are able to write good instructional objectives, determine the content type and process level of the learning task and select strategies appropriate to the task. The number of strategies identified ranged from 5-9 for remembering tasks and 14 to 19 for deep or meaningful tasks. These figures suggest students have an increased awareness and range of strategies, more appropriate usage and are able to use a greater number of strategies per task."

APPROACH TO LEARNING	SELF-CONCEPT	METACOGNITION
Surface Motive Surface Strategy Deep Motive Deep Strategy Acieving Motive Achieving Strategy	Perception of peer attitudes Perception of authority-figure attitudes Assertiveness Personal attitudes Degree of Structure Perception of own ability Anxiety level Motivation View toward hard work	Organization Awareness & use of strategies Evaluating Monitoring

In the U. S., ADM work (Section 1.0) has shown that the quality of decision making can be enhanced with the appropriate development of cognitive skills in a classroom setting. It appears that the high quality of information processing skills being taught at Massey

University may offer an attractive growth direction for decision making training in the U. S.

B. Intuitive Decision Making Testing

In the 1980s, the application of expertise and intuitive decision making gained acceptance in guiding executive decision making for a wide range of industries. A successful field testing of intuitive decision making skills of over 3000 managers throughout the U. S. in a wide variety of organizational settings was a part of that acceptance effort (Agor, 1986). These settings included business, government, education, military and health and a wide range of management levels. *This experience and the positive results once again (as with the Brain Gym, Thought Trials, etc.) suggests an opportunity exists to transfer developments in appropriate testing or training methods from other fields to aviation without repeating all of the learning curve work at great financial and time costs.*

When the executives who scored in the top 10 percent in intuitive ability are tested, the results overwhelmingly indicate that these executives do use their autonomous, adaptive procedural reasoning to guide their most important decisions. Not only do the vast majority of these top executives admit that they use intuition to help guide their most important decisions, but they go on to specify the situations and contexts in which they find their intuition is most helpful:

- When there is a high level of uncertainty.
- When there is little previous precedent.
- When the variables are not very scientifically predictable.
- When "facts" are limited (i.e., knowledge lean situations).
- When "facts" do not clearly point the way to go (ambiguous).
- When there are several plausible alternative solutions to choose from, with good arguments for each.
- When analytical data are of little use (e.g., new trends are emerging)
- When time is limited and there is pressure to be right.

It is also significant to note that when these top managers intuitively "know" they have reached the correct decision, they share a "consensus set" of feelings that tell them so: a sense of excitement--almost euphoria; a total sense of commitment; a feeling of total harmony; warmth and confidence; a burst of enthusiasm and energy that "this is the right solution." Pilot's surviving abnormal emergencies and chaotic, multiple failures have reported very similar feelings. Alternatively, when they sense an impending decision may be an incorrect one or that they need to take

more time to adequately process the cues and information they are receiving, these managers speak of feelings of anxiety, mixed signals, discomfort, or an upset stomach.

Clearly there are parallels in the executives use and need for intuition to what we have discussed for expert pilot decision making. Even more dramatic are the direct parallels to the executive's rationale for when intuition is critically important and the situations faced by pilots when "things start to go wrong". The unprecedented, time pressured, knowledge lean situations faced by pilots in emergency situations, especially chaotic, multiple failures for which they have no previous experience or training, are precisely when they need to be able to call upon and use the higher form of expert thinking called intuition.

C. Proposed Cognitive SOARing Testing and Training

This section describes a pilot expert decision making test instrument which emulates and includes the intuitive assessment aspects of the Agor Intuitive Management (AIM) Survey. However, it will go beyond the identification of that specific trait and test the cognitive areas (Sensing, Organizing, Analyzing and Responding) in which pilots are strong and weak so that individuals, instructors and researchers can focus decision making training in those areas needing work.

Part I of the SOARing self-test would be derived by careful examination of the Meyers-Briggs Type Indicator (MBTI) and selection of three questions in each of the four scales to determine the pilot's basic decision making type as done by the AIM. Based on Agor's success with executive decision making testing, the selection of the 12 questions could be accomplished jointly by the contractor and the FAA Technical Monitor. The selected questions and the rationale for selection could be validated with personnel from the Center for Applications of Psychological Type in Gainesville, Florida. This is a non-profit organization whose purpose is to further research and education on the Myers-Briggs Type Indicator. Based upon the results of these reviews, the questions selected, the number of questions, etc. could be revised. Final selection could also be reviewed with FAA examiners, Certified Flight Instructors and Flight Training Schools as deemed necessary.

An understanding of a pilot's type in general and his own preferences in responding to task demands, will help define what individual areas of EDM require training. It will also indicate what areas of intrapersonal skills are strong and weak so that any crew resource management training can stress these areas. Finally, it will form the

foundation for closer examination of how these preferences are affecting information processing, problem solving and decision making in Part II of the test.

Part II of the SOARing self-test will consist of 12 flight scenarios selected from actual occurrences, incidents and accidents (and again similar to the successful ADM written self-test). The criteria, construction and development of these scenarios is described in detail in Appendix F. Each scenario will be presented in written form followed by a series of questions dealing with Sensing, Organizing, Analyzing and Responding to the tasks demanded of the pilot in the normal, abnormal or emergency situations described.

Sensing in this test measures the pilot's ability to identify a problem or an impending problem and is the first step in deciding to do something about it. The critical characteristic that will be evaluated by the test is the amount of information that is "attended to" without requiring controlled or focused attention. Since the amount of time pilots spend actively attending to sensory inputs vs. passively monitoring the cues and context of a situation varies directly with knowledge, experience, training and currency, this scale will be the first differentiator in expert vs. novice decision making capabilities. Specific questions in each scenario will deal with subtle information that the less experienced pilots will have to spend more time

SOAR SELF-TEST SCALES

|		
1. SENSING AND INTERPRETING CUES AND CONTEXT	S	ACTIVE —————— PASSIVE
2. FILTERING AND ORGANIZING INFORMATION	O	SERIAL —————— PARALLEL
3. ANALYZING AND PROCESSING INFORMATION	A	CONCEPTUAL —————— PROCEDURAL
4. DECISION MAKING, PROBLEM SOLVING AND RESPONDING	R	COGNITIVE —————— AUTONOMOUS

"attending to". The nature of the questions, and the timed test responses will result in scores which are rated on a scale of from 1 (the least likely response to 5 the most likely response). These scores will be accumulated with the remaining three decision making parameters to produce an assessment on each individual scale as well as an overall EDM pilot rating.

Organizing involves the ability to filter, sort and prioritize sensed information as a critical part in the understanding of the situation. The basic characteristics that will be involved in this part of the self-test will be whether pilots use serial, checklist processing of all relevant alternatives or whether they use non-linear, parallel, inferential information processing. Again, the responses will be scored numerically from 1 to 5 and accumulated for individual EDM self-assessments and overall EDM ratings.

Analyzing and processing of the available information relies on the type of knowledge stored and how it can be retrieved. The pilot's style can vary from pure application of flying skills to the use of rules or heuristics and finally to the application of a combination knowledge, skills and rules. This scale will rate the pilot's ability to use large procedural "chunks" and relevant pattern recognition techniques to reduce the cognitive searching and deductive reasoning involved in processing many and diverse elements of conceptual knowledge.

Responding is the most critical of the EDM steps. It requires that the pilot take some action and then monitor and evaluate the effect of that action. The test scenarios will evaluate this capability by offering opportunities for both selecting one of several "alternative solutions" or creating an individual solution to the problem presented. The scale will rank the pilots according to the degree of cognitive, associative, autonomous and intuitive ability applied based both upon the number of alternatives attempted and the total time to reach convergence on the a solution.

Although a score will be associated with each preference, it only indicates how consistently a pilot chooses one type of decision making over another in each category. High scores generally mean a clear preference for expert vs. novice characteristics in a specific area. However, there is nothing wrong with low scores, especially in less experienced pilots.

EDM RATING METHOD

SOAR ing SELF - ASSESSMENT TEST
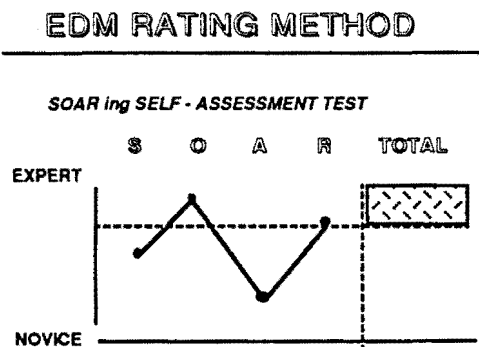
The real importance of the profile is to indicate a pilots ability to solve problems and make decision using a specific type of decision making and problem solving. Expert pilots need to know how to use the full range of their "thinking" capabilities depending on the cues, context, familiarity and difficulty of the situation. The important point is that research in many fields has shown that this is a skill which can be acquired through practice and training. That is the ultimate purpose of this self-test exercise. The continued development of these testing and training materials is proposed as Phase III of the current FAA research.

6.0 CONCLUSIONS and RECOMMENDATIONS

This section summarizes what pilots need to know to use the full range of their "thinking" capabilities. The expert pilot's decision making "adapts" depending on the cues, context, familiarity and difficulty of the situation. Research in many fields has shown that at least some of the expert decision making skills can be acquired through practice and training. The ultimate purpose of this report is to suggest a starting point for developing EDM training for pilots. The following conclusions and recommendations are tailored to that purpose.

CONCLUSION 1: **Enhanced memory and problem solving training are required to expedite development of Expert Decision Making (EDM) in novice pilots.**

The study of cognition has identified the importance of sensory, short term and long term memory in the development of expertise. Since memory is the fundamental process that accounts for the differences in expert and novice decision making, the use of these systems in information processing and problem solving is critical to training expert pilot decision making. Attention, perception, pattern recognition, associations, elaborations, inferences and how basic conceptual knowledge is stored all impact recall and the level of automaticity in decision making. Developing these characteristics into an integrated set of cognitive procedural knowledge is required to progress to the next stage of decision making training.

RECOMMENDATION 1 -- **Aviation problem solving and pilot memory training courses should be developed.** Three non-aviation cognitive training programs which offer potential insight for new EDM training paradigms were reviewed in Section 5.2. These and other programs which have documented improvements in attention, memory and problem solving should be explored and adapted to prototype EDM courseware.

CONCLUSION 2: **The reliance of EDM on knowledge based on experiences and sensory stimuli make the selection of training media extremely critical.**

This study has shown that experts structure information differently in memory and integrate new information rapidly. Development of EDM is influenced by the cues and task demands encountered in the course of experience and training. Expert pilots change a structured, deductive process into a cued recall task by building mental representations of meaningful relationships in a situation. These relationships are more than the cognitive knowledge perceived by novices in the

same situation. They provide keen, quick insight and almost a direct perception of the proper course of action. Expert decision making in new situations with ambiguous information and rapidly changing cues requires an adept use of this process. The expert's perceptual superiority, fast access, adaptive decision making requires broad exposure to meaningful sensory cues in operational contexts to develop this inferential capability.

RECOMMENDATION 2 -- **The development of a knowledge based CBT or IVT expert training device should be initiated.** The fields of Activity Based Learning (ABL), Computer Based Training (CBT) and Interactive Video Training (IVT) offer near term, cost effective alternatives which are attractive to both air lines and general aviation pilots. Two example CBT systems were discussed in Section 5.2.

CONCLUSION 3: Experience since 1986 with ADM training in both civil and military U. S. operations has shown that **decision making can be taught and this training reduces the number of human error accidents.**

Prior to the development of ADM training, it was widely held that good decision making could only be learned through experience. The 15 years of ADM work has contradicted this logic by showing that some aspects of good decisions can be trained. However, we have now realized that there is another, more subtle impact of experience on decision making in which the steps of the process are hidden in the perceptual and procedural portion of human information processing. The expert's superior perceptual ability is aided by the ability to store and access chunks of data in short term memory. The superior problem solving ability is speeded up by the storing of patterns or schema of related events, facts and results in long term memory. Experts also develop superior situational awareness capabilities which including self regulatory processes that free working memory for higher levels of conscious processing. These abilities include: planing ahead, efficiently monitoring one's time and attention resources and monitoring and editing one's efforts to solve a problem.

RECOMMENDATION 3 -- **A second generation ADM or EDM training manual should be developed in response to industry's request for additional material and to continue the safety improvements generated by this training.** This manual should focus on the superior expert memory, information processing and problem solving characteristics identified in this report. Much of the material needed for this manual has already been created during Phases I and II of this project. Reformatting the EDM research into a training manual could be accomplished in a timely, cost effective manner.

CONCLUSION 4: An FAA EDM training program should be developed and tested. Courseware, an instructor's syllabus, student manuals and self test materials are required.

The successful use of ADM training material in the U.S. and internationally has shown that the quality of decision making can be enhanced with the appropriate development of cognitive skills in a classroom setting. Based on the research from Phase I and Phase II of this project, it appears that metacognition training (under evaluation using novice pilots at Massey University in New Zealand) and intuitive decision making training (i.e., training based on experiences and acquired through sensory contact offer significant potential for further reductions in pilot error accidents related to decision making. These include providing the novice pilots the knowledge and procedures necessary to assess, interpret and understand their own "thinking" or decision making processes. The high level information processing skills being taught at Massey include the individuals approach to decision making, self-assessment and metacognition skills in a time-pressured, dynamic decision making situation.

RECOMMENDATION 4 -- The aviation EDM training/testing conducted at Massey University in New Zealand since 1990 should be the starting point for an FAA EDM course for pilots. The Intuitive Decision Making testing from non-aviation fields should be reviewed for possible relevance or enhancements of the Massey program.

CONCLUSION 5: A written self-assessment test would be the most expeditious and cost effective method of raising the awareness of aviator EDM characteristics and initiating EDM training.

SOAR SELF-TEST SCALES

1. SENSING AND INTERPRETING CUES AND CONTEXT	S	ACTIVE ——————— PASSIVE
2. FILTERING AND ORGANIZING INFORMATION	O	SERIAL ——————— PARALLEL
3. ANALYZING AND PROCESSING INFORMATION	A	CONCEPTUAL ——————— PROCEDURAL
4. DECISION MAKING, PROBLEM SOLVING AND RESPONDING	R	COGNITIVE ——————— AUTONOMOUS

The application of the knowledge of expertise to the field of Aeronautical Decision Making identified four aspects as critical to Expert Decision Making. These were: Sensing, Organizing, Analyzing and Responding to the cues, context and demands of the situation. These four mental aspects are integral to the preparation, analysis and execution of decisions for normal, emergency, and, abnormal or novel situations. They also can form the basis of both a testing and training program for EDM. The type of problem solving behavior where solutions are developed under time pressured, ambiguous circumstances has been identified as Type C problem solving behavior. Successful training of this behavior has been

31

demonstrated in other fields. The transfer of this training to aviation was initiated during Phase II of this study and was termed Cognitive SOARing.

RECOMMENDATION 5 -- Continue development of the Cognitive SOARing self-assessment test initiated for assessing individual pilot EDM capabilities. Integrate this self-assessment procedure into both the future EDM training manuals and course material developed.

CONCLUSION 6: Selecting realistic EDM scenarios with critical events and performing a cognitive task analysis of novice vs. expert decision making for these events is a basic requirement for future EDM training development.

The central problem when studying EDM in aviation is that the process to be studied occurs in complex and highly interactive situations. The general solution to this problem (developed in other areas of expertise) is to analyze carefully the real life events requiring EDM and to identify brief segments of the expert's behavior that corresponds to a natural occurring task. This type of cognitive task analysis was suggested as the next significant step in the development of decision making training by the participants in a 1992 ADM workshop (Adams & Adams, 1992). In many task analyses it is possible to explicate a limited number of sequences of thoughts that will adequately describe how subjects generate the best answer or some alternative answer for a given task. these alternative thought sequences make it feasible not only to describe other subjects' efforts to complete the task, but would provide the potential of giving feedback to subjects generating sub-optimal answers/actions. Analyses of expert performance using this type of task analysis has revealed a perspective of general characteristics of experts' cognitive processes.

RECOMMENDATION 6 -- The design of EDM training scenarios and assessment methods should be initiated in parallel with training materials, training tools and courseware development. A methodology and implications of developing EDM scenarios are presented in Appendix F. This type of methodology is required for Activity Based Learning (Recommendation 2), a second generation training manual (Recommendation 3) and self-assessment written testing (Recommendation 5).

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APPENDIX A

## EXPERT INFORMATION ANALYSIS AND EDM DEVELOPMENT

Cognitive psychology is the study of how people think. Cognition in its simplest definition is "thinking". Processing is the mental function that takes in sensory inputs and transforms them into information that can be used in thinking. Sensory inputs include visual, aural and kinesthetic (vibration, acceleration, etc.) data from the environment. Processing involves sampling data from the situation and identifying it as normal or abnormal. Decision making includes anticipating problems or problem solving if one already exists.

DEFINITIONS

- COGNITIVE PSYCHOLOGY -- How People THINK
- COGNITION = Thinking — Reception / Processing / Storing / Remembering
- PROCESSING = Problem Solving / = Decision Making — Novice / EXPERT

Captain Al Haynes' information processing abilities were discussed in Section 3.1 as one example of cognitive SOARing: Sensing, Organizing, Analyzing and Responding to a highly stressful and time critical decision making circumstance. However, pilots and crews use these four steps on a daily basis for both normal and emergency problem solving and decision making. **The following discussion addresses the unique mental abilities that allow expert pilots to be successful in routinely executing these steps.** The purpose of this discussion is to identify the basic elements and concepts which heighten a pilot's information processing abilities.

A.1 Information Processing Systems
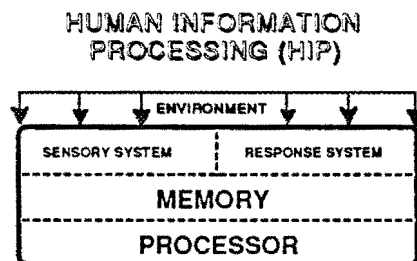
HUMAN INFORMATION PROCESSING (HIP)

	ENVIRONMENT	
SENSORY SYSTEM		RESPONSE SYSTEM
MEMORY		
PROCESSOR		

The study of cognition over the past 40 years has identified the importance of four systems used in thinking or "information processing". These systems are illustrated in the Human Information Processing (HIP) diagram.

Basically, these systems include: the sensory systems (visual, auditory, seat-of-the-pants, etc.), the memory systems (long term, short term and sensory memory), the processor and the response systems (motor events, communications, etc.).

HIP -- MEMORY

| SENSORY	WORKING	LONG TERM

MEMORY Human memory is the fundamental process that accounts for the differences in expert and novice pilot thinking capabilities. Central to that process is the way information is perceived and stored or organized. Perception relies on the abilities of the sensory memory to recognize and sort information. Organizing information requires the resources of the short-term and long term

memory systems. Both types of memory are critically impacted by the quantity and type of knowledge available. In fact, the topics of type of knowledge, how it is represented in memory, how people tie it together and how they remember it are central to the understanding of cognition in general and how pilots think in particular.

Sensory memory insures that enough retention to allow sufficient spare processing capacity is available for "handling" new inputs. Visual or iconic memory is available for 0.5 to 1.0 seconds and auditory or echoic memory for 2.0 to 8.0 seconds. Sensing of information is a function of knowledge, attention, perception and expectations. For example, the casual mention of your name in the noisy environment of a reception or cocktail party will quite often "pull" you into a conversation you were not even aware of prior to hearing your name. This "cocktail party effect" illustrates the importance of automatic attention to your perception of contextual cues of any situation. Expectations also impact your sensing powers. Since each pilot has a unique background of knowledge, training and experience, expectations based on that background impact the ability to respond in a timely fashion to specific situations.

HIP -- SENSORY MEMORY

A lot of information received, a small amount "attended to" and remembered.
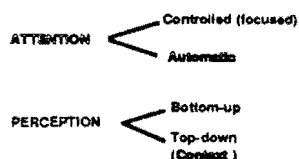
ATTENTION
- Controlled (focused)
- Automatic

PERCEPTION
- Bottom-up
- Top-down
  (Context)

The basic characteristic of sensory memory that is important for pilots to be aware of is that a lot of information is "sensed" or received, but only a small amount is "attended to" or remembered. An example of this phenomena is the large amount of digital and analog information sampled or sensed by pilots in a typical scan of the instruments. Most of the needle, ball and airspeed information (if within limits) is simply observed and noted in passing. However, if crosstrack deviation or altitude are outside desired values, the pilot is generally quick to notice and make appropriate corrections. This is an example of controlled or focused attention which involves a conscious decision to respond and usually occupies sensory memory on a single task at any given time.

On the other hand, while scanning the instruments, listening to the radio and developing a mental picture of the flight's progress, a pilot will easily "pick-up" his call-sign when it is uttered by ATC and immediately respond. This is an example of passive attention which does not require dedicated sensory memory until stimulated by salient cues. The amount of time pilots spend actively attending to sensory inputs vs. passively monitoring the cues of a situation varies directly with knowledge, experience, training and currency. Dedicated time spent focusing on individual cues and responding is time taken away from situation monitoring or passive situation assessment. For these reasons, "Attention" is one of the differentiators which can be used to identify experts vs. novices. Attention can also provide the first part of a training program designed to lessen the reliance on experience as the only means of attaining expert performance.

Short-term memory Short and long term memory should not be thought of as different places pilots "put" facts or different types of information. Rather, the difference in these two memory systems is based in the level of activation of the knowledge at any given time. The Short term or Working memory system consists of a limited amount of information that is in a special "active" state available for immediate use. Working memory has two distinctive characteristics. It is limited in both capacity and time. A typical 20 year old student pilot will be able to remember from five to nine items for a transient period of from 18-20 seconds.

HIP -- WORKING MEMORY

A limited amount of information in a special "active" state available to be used.

• Transient or Short term: 18 - 20 seconds

• 7 ± 2 items or " Chunks "

Chunks = Units stored in long term memory

e.g., 4 symbols (PBI, 9L , 080, 12)
6 words (TRAFFIC, HEAVY, JET, NINE,...)
3 four syl. words (AVIATION,...)
A 19 word sentence (American seven twenty cleared to Miami Airport via Lake Charles transition, maintain....)

As pilots get older, both the number of items in Working memory and the duration of their active state decrease. However, this is not an all bad news story since, once again, experience and training can have a major impact on how much useful information each "item" contains. In fact, experts in all fields develop the ability to store "chunks" of related data which novices might be forced to store individually to retain their active state (see the chart for examples of chunks). For example, the expert pilot tuning in the ATIS broadcast prior to entering a terminal area knows to expect: time, ceiling, visibility, temperature, dew point, wind, altimeter and runway-in-use information and will not be overwhelmed with the task of "remembering" the chunks that are transmitted. Conversely, a novice may have to write down the significant ceiling, visibility, wind, altimeter and runway data.

In summary, the short term memory provides active, usable chunks of information in a state of readiness to be used. The precise content, organization and use ability of each chunk is tied directly to exposure and practice. Therefore, pilot training and especially decision making training could benefit by re-examining the criticality of information chunking and train novice pilots earlier in the necessary short term memory skills.

HIP -- LONG TERM MEMORY

Not encyclopedic, but "reactivation and reconstruction".

• Recognition -- Discriminate only

• Recall -- Generate and Discriminate

fishnet theory   Scheme

Long term memory The long term memory system is not simply an encyclopedic repository of facts. Rather, it is stored knowledge (including factual, procedural, experiential and emotional) that individuals have stored in related groups and have the ability to reactivate. Reactivation can be initiated by the cues (mental or physical), the context of a situation (standard procedure or emergency) and the pilot's abilities to make associations, retrieve and activate the needed knowledge. Whereas the chunks of information in short term memory are active by definition, the level of activation of the knowledge in long term

memory is based upon the recency with which it has been learned and experienced and the number of times it has been used (or practiced) in new situations.

Long term memory, then, depends on the pilot's ability to respond to new demands for information through his abilities of recognition and recall. Recognition powers allow the pilot to discriminate between the new situation and similar or different "memories" which might apply. Recall allows the pilot to not only discriminate, sort and prioritize the information that is needed, but also aids in the generation of new ideas, solutions or actions required to respond to the demands of situations previously not experienced.

Once again, expert pilots (as well as experts in other fields) have developed superior long term memory organizational capabilities which facilitate recognition and recall of their knowledge. Experts use **schema** (a modifiable information structure or concept based upon knowledge that is experienced) to recognize and interpret the cues and context of a new situation based upon their related knowledge. That is, experts experience and store interrelationships between objects, data, situations and results. This schema theory states that experts store schemata for recurrent situations that expedite decision making and problem solving. The simplest example of this ability in aviation is the expert pilots superior knowledge of procedures for both normal and emergency situations. More complex examples would include the experienced pilot anticipating entering a thunderstorm, anticipating wind shear on landing or anticipating in-flight icing conditions. These abilities are also manifested by the expert pilot's traits of superior situational awareness (i.e., all elements including: the aircraft, the environment, self, etc.).

Furthermore, the capability of experts to **fast-access** their knowledge facilitates perception and leads to the **reduction of the role of memory search and general processing**. Although the novice and expert have equal capability for cognitive processing, novices typically use lots of search and processing in a less focused, more general manner. The outstanding performance of experts is derived from how their knowledge is structured for: Retrieval, Pattern Recognition and Inference.

This expert capability manifests itself in the ability to intuitively respond to patterns without decomposing them into component features or problem elements. An example of these abilities would be the expert's ability to respond to loss of an engine on takeoff without consciously "thinking through" the engine out procedure. This understanding occurs effortlessly due to discriminations resulting from prior, concrete experience.

In summary, expert pilot's have tailored their use of long term memory by storing organized patterns of related facts, events and feelings which affect both recognition and recall. Their ability to fast access patterns of aviation knowledge is expedited by the **associations** with cues and context of new situations which stimulate the recall process. Although the associations (or concept elaborations) are predominantly based upon experience today, training aimed at replicating this ability is not an
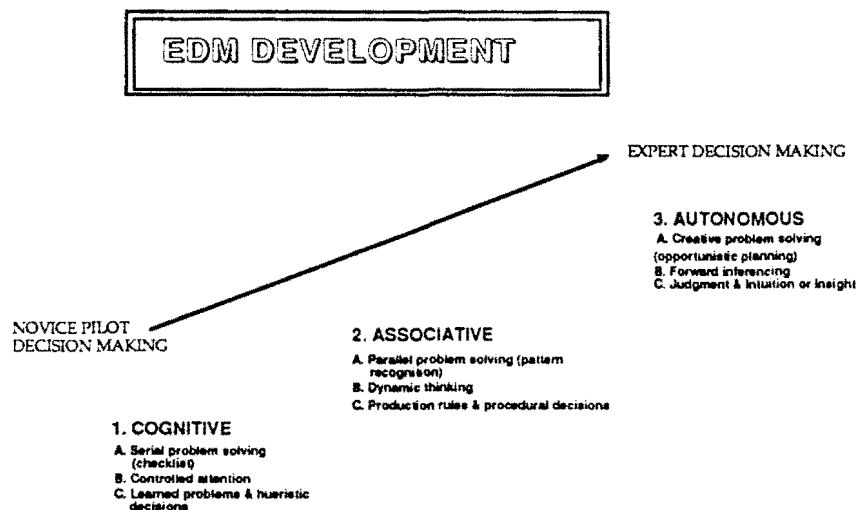
HIP -- LONG TERM MEMORY

- ORGANIZATION AFFECTS BOTH R & R
- ELABORATIONS EXPEDITE RECALL
- INFERENCES AID ELABORATIONS & RECONSTRUCTION
- CUES & CONTEXT CAN MAKE RECALL EASIER THAN RECOGNITION

unreasonable goal. In addition to the elaborations, the expert's ability to use **inferences** to aid reconstruction of similar problems and solutions could also comprise part of this training. The final important element of such a training program would be to teach the novice to go back to the cues and context of the current problem to affirm that his response is the correct one.

A.2 EDM DEVELOPMENT

From a cognitive psychology perspective, the process of developing more sophisticated decision making involves three stages of expert problem solving skills (Anderson, 1985). These are *cognitive, associative and autonomous* . During the first, *cognitive* stage, novice pilots commit to memory a set of facts relevant to a desired skill. They typically rehearse these facts as they first perform the skill. For example, novice pilots learning stall recovery will memorize: recognize the stall, lower the nose, apply full power, level the wings and minimize altitude loss. In this stage, they are using their general aeronautics

EDM DEVELOPMENT

EXPERT DECISION MAKING

3. AUTONOMOUS
A. Creative problem solving (opportunistic planning)
B. Forward inferencing
C. Judgment & Intuition or Insight

NOVICE PILOT DECISION MAKING

2. ASSOCIATIVE
A. Parallel problem solving (pattern recognition)
B. Dynamic thinking
C. Production rules & procedural decisions

1. COGNITIVE
A. Serial problem solving (checklist)
B. Controlled attention
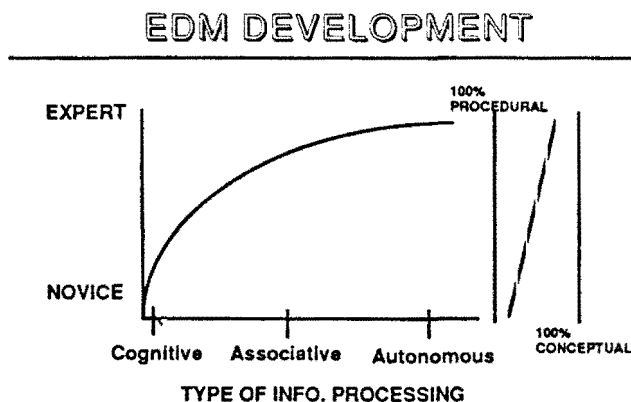C. Learned problems & heuristic decisions

knowledge to guide their solution to loss of lift over one wing, and solve a specific problem, how to keep the aircraft flying. The problem solving capabilities and level of expertise in this stage are very basic. These skills rely principally on serial (checklist) type problem solving, a lengthy general search of conceptual knowledge and controlled attention throughout the resolution of the problem. As the experience base increases, the cognitive decision maker develops heuristic decision making capabilities for those learned problems that have been practiced or encountered.

The **second**, or *associative* stage, has two important characteristics. First, errors in the initial understanding and performance are detected and gradually eliminated. The novice pilot learns to coordinate the nose drop, power application and rudder application for a smooth stall recovery. Second, the connections between the various elements required for successful performance are strengthened. The pilot

40

does not sit for a few seconds trying to decide which action to perform first after lowering the nose. Basically, the outcome of the *associative* stage is a learned procedure or production rule for performing a desired response to a known situation. In this stage, the conceptual knowledge is transformed into a procedural form which provides the pilot with the capabilities for more dynamic thinking and parallel processing. However, the procedural form does not necessarily replace the conceptual knowledge. Rather the two forms coexist and are available when needed for a task. For example, the low time pilot can fly the airplane while simultaneously talking to ATC and navigating. All the while, he still remembers the rules of aerodynamics, the characteristics of a stall and the recovery process.

The **third** cognitive stage occurs when the problem solving procedures become faster and more automated. There is not necessarily any sharp distinction between the associative and *autonomous* stages of expertise. Rather, the *autonomous* stage evolves from the repeated application of known patterns and their associative use to achieve solutions. The use of conceptual knowledge often disappears during this stage, at least for some tasks. In fact, the ability to verbalize knowledge of the procedure can be lost. Furthermore, expert decision making appears to develop continually in a specific area like aviation. Throughout the development, the skill gradually improves.

Ultimately, the skill can be extended to the ability to respond to cues not previously encountered and to develop new, creative (opportunistic) solutions applicable to previously unencountered (novel or chaotic) situations. In general, expert decision makers have the ability to adapt to the inherent demands and constraints of a task. If the task can be done most efficiently with forward reasoning and the development of new production rules based upon procedural knowledge, the expert will search forward; if backward search of conceptual knowledge is better, the expert searches backward. If certain patterns of cues are crucial to performing the task well, the expert will be apt to perceive and remember them; if patterns are not so important, the expert will not selectively process them. Most importantly, the expert decision making capabilities occur so fast that they appear to take on the characteristics of insight or intuition.

EDM DEVELOPMENT

41

APPENDIX B

CHARACTERISTICS OF INTUITION

The status of current work on intuition is thoroughly summarized in "Intuition: How We Think and Act" (Bastic, 1982). This is an exhaustive literature search of 2,692,000 articles, reports, and theses from five data bases. Only 91 had the word "intuition" in the title or description. Of these 24 were useful studies of intuition. The remainder only referred casually to the word intuition. From this extensive review, Bastic compiled 20 summary properties of intuition. The properties are

INTUITION PROPERTIES	EDM APPLICATION
1. QUICK, IMMEDIATE, APPEARANCE	
2. EMOTIONAL INVOLVEMENT	
3. **PRECONSCIOUS PROCESS**	AUTONOMOUS PROCESSING
4. NOT ANALYTICAL PROBLEM SOLVING, LOGIC OR ABSTRACT REASONING	
5. **INFLUENCED BY EXPERIENCE**	KNOWLEDGE ORGANIZATION & ELABORATION
6. EMOTIVE NOT TACTILE	
7. **ASSOCIATED WITH CREATIVITY**	ADAPTIVE EXPERT
8. ASSOCIATED WITH EGOCENTRICITY	
9. INTUITION NEED NOT BE CORRECT	
10. **SUBJECTIVE CERTAINTY OF CORRECTNESS**	PILOTS ARE SELF-ASSURED & OPTIMISTIC DECISION MAKERS
11. RECENTERING	
12. EMPATHY, KINESTHETIC OR OTHER	
13. INNATE, KNOWLEDGE OR ABILITY	
14. PREVERBAL CONCEPT	
15. **GLOBAL KNOWLEDGE**	LARGE MEANINGFUL PATTERNS
16. **INCOMPLETE KNOWLEDGE**	ILL-STRUCTURED, AMBIGUOUS AND KNOWLEDGE LEAN PROBLEM SOLVING
17. HYPNOGOGIC REVERIE	
18. **SENSE OF RELATIONS**	PATTERN RECOGNITION
19. **DEPENDENCE ON ENVIRONMENT**	CUES AND CONTEXT OF SITUATIONS OR DECISION TASK DEMANDS
20. TRANSFER AND TRANSPOSITION	

repeated here with those properties most applicable to how expert pilots think indicated in **bold** type. These properties are presented as a set of "descriptors" of intuition, but are not independent. Rather, they are related in many, complex ways some of which will be explained in the text which follows. Where there is an apparent impact on Expert Decision Making and an opportunity for EDM training, this will also be described.

PROPERTIES 1 and 2 -- These properties reflect the immediate knowing or perception of a solution to a problem, or what action to take in a situation, without the conscious use of reasoning. This "instantaneous apprehension" is the Eureka experience we are all familiar with. The closest scientific term that describes this experience is insight which Webster's defines as "a clear understanding of the inner nature of some specific thing". From an operational aviation perspective, we will use intuition and insight as interchangeable.

PROPERTY 3 -- Preconscious is used to refer to material, which, though at the moment it may be unconscious, is available and ready to be consciously used in decision making (Drever, 1974). **Preconscious process** refers to two properties of intuition: preconscious information intake, and preconscious intuitive processing of this information. The preconscious processing property underlies the EDM capability for autonomous problem solving. In this sense, preconscious means direct knowledge of an empirically derived decision without conscious, analytical awareness of its basis. This preconscious property is, however, based upon principled knowledge such as aerodynamics, gravity, Newton's Law, etc.

PROPERTY 4 -- Intuition **contrasts with abstract reasoning, logic and analytical thought.** Although there is evidence that shows either an intuitive or abstract, analytical approach to problem solving is a stable cognitive style, there are basic observable differences. The analytical process of decision making is a step-by-step process which normally just compares two elements at a time. Intuitive processing is based on an overall impression or a knowledge state that associates all the elements of a specific field. Pilot intuition uses parallel processing based upon associations and non-linear feedback from the whole field of aviation knowledge, simultaneously. This process accounts for the dramatic difference in the speed of processing. Since the concurrent feelings associated with the situation have been associated in memory by the pilot's unique experience, original connections or associations can result. However, these elements are related by a common subjective feeling, not by logic.

PROPERTY 5 -- Intuitive decision making is **dependent on the past experiences** and the present situation of the pilot. Stimuli (cues) from the environment and goals (context) of the situation are used in memory to "perceive" the characteristics of the "whole" problem. The experience based "perception" includes the pilot's motor, emotional and cognitive cues as a part of the problem categorization and decision making process. Past experience can also interfere with perceptions of a situation when anxiety, stress, emotional blocking or cognitive dissonance associations are triggered. What is intended by the use of intuition in the decision making process is

a perception of the essential requirements of a problem so that past experience can be applied in a manner appropriate to the present situation. The full implications of the dependency of expert decision making training on the ability to replicate this "whole" experience may be crucial to future training development.

PROPERTIES 6, 9 AND 12 -- These properties indicate that intuition is a sense of feeling for patterns or relationships. The subjective associations of feelings between the elements of a situation seem to hold the elements in a pattern or schema for use in later processing. These insights are not necessarily correct due to: the emotional involvement; the lack of total representation of the whole problem; or, empathy of the pilot with the objects or events of the situation.

PROPERTY 7 -- The **creativity** involved with intuition is essential to adaptive expert decision making. The pilot faced with a novel situation (one for which he has not been trained or has not experienced) must be able to combine his knowledge, training and experience derived patterns in a timely, strategic manner. This has been referred to as "opportunistic planning" in the EDM development discussion. However, these plans derived from preconscious mental activity may not always be correct. Therefore, in aviation, mathematics and scientific fields, the creative decision is always followed by logical, empirical verification of the intuition.

PROPERTY 8 -- The **egocentricity** property of intuition simply means that situations that prove embarrassing or in which the pilot is the center of attention appear to be remembered better than less "ego-involved" experiences. Pure egocentricity is lack of the ability to differentiate self interest from the perceived environment or situation. The extreme result of this property would be intuitive thought dominated by preoccupation with personal satisfaction.

PROPERTY 10 -- Irrespective of the objective correctness of the intuition, it is accompanied by a feeling of confidence related to the relief of anxiety and tension associated with solving an ill-structured problem. This **subjective certainty** has been documented in several aviation "saves" where the pilot quickly responded to multiple emergencies with confidence that he would safely land the airplane but without any logical or objective reasons for that confidence. This confidence or optimism based upon unsubstantiated evidence is often an accurate predictor of correct insights or intuitions.

PROPERTY 11 -- **Recentering** is sometimes called "cognitive reorganization" (Watson, 1974). It is the experience that suddenly something changes in a situation or problem into one that is familiar and can be dealt with when, prior to

recentering, there was a feeling of frustration and inability to cope. This term has also been applied to solutions or ideas that appear "out-of-the-blue" after the problem has been mentally shelved or the pilot is involved with some activity that is apparently unrelated to the original problem.

PROPERTIES 13 & 16 -- Intuitive knowledge is sometimes considered to be **innate or instinctive**. This type of knowledge is used to arrive at judgments or solutions for which the pilots knowledge is too incomplete to justify a decision. "Woman's intuition" falls in this category. This property also falls under the definition of "primary intuition". This discussion of the role of intuition in developing EDM does not include innate or instinctive knowledge or ability.

PROPERTY 14 -- This property of intuition, **Preverbal**, is used for two reasons. First, because intuitive perception and processing is speedy on many parallel associations where the verbal mode of processing is linear and slow in comparison. This speedy parallel vs. slow linear comparison is also a reason behind the contrast of intuition with logic. Second, the amount and quality of knowledge which the pilot receives through intuition makes its complete verbalization impossible. This property is not critical to the EDM training objectives of this project.

PROPERTY 15 & 18 -- The essence of intuition and autonomous cognitive processing is in the wholeness of perception, the completeness of ideas, the involvement of feelings and the importance of experiences which comprise the **Global Knowledge** necessary for specific situations. The process of intuition is not a linear step-by-step process but a global, non-linear process using knowledge and situation cues to form a whole perception of the situation. The intuitive process integrates the information one already has, the new associations between this information which provides new insights, and shreds of information which formerly had no meaning to develop new patterns of knowledge and new solutions to novel problems.

PROPERTY -- 17 **Hypnogogic reverie** is the apparent association of images which appear during very relaxed, near sleep like states. We are not concerned with these from an EDM perspective.

PROPERTY -- 19 The **environment** is especially important to the intuitive process in three ways. First, the specific training and scientific culture that promote and contribute to intuitive thinking are necessary for the pilot's interpretation of the situation. Second, the environment should be relaxed, familiar and free from stress.

Third, this relaxed environment can spark the Eureka experience resulting from the unique combination of circumstances and experience.

PROPERTY -- 20 **Transposition** does not necessarily indicate the presence of intuition or insight. Insight is not only perception of relations, but also awareness of relations. It is difficult to interpret this property to the analysis of EDM.

Now that we have reviewed the important characteristics of Intuition (i.e., 3, 5, 7, 10, 15, 16, 18, 19) as they relate to EDM, the real question is how past experiences are used to solve present problems. The theory of intuition explains that past experiences are grouped into specific schema. These schema are the data with which pilots approach new situations. It remains the problem of the current research to define how past experience is used to define present goals. Cognitive psychology research has shown that "learning by doing" or activity based learning which associates ideas with experiences (which can later be recalled) is necessary to achieve these goals. In addition, the dependence of intuition on knowledge that is learned through experiences and sensory contact, reinforces the need for training that includes pilot activities both physical and mental.

Once the intuitive ties have been established between the elements of any new experience and the pilot's knowledge base, it is highly probable that the relationships between some of the elements of the problem in the current situation will be analogous to previous situations. Since experience is not based on isolated elements but of elements related in some fashion, the power of intuition is somewhat guaranteed.

APPENDIX C

NON-AVIATION COGNITIVE TRAINING ACTIVITIES

Three approaches to enhanced cognitive training are described in this section. They are examples of non-aviation research that may have applicability to aviation.

COGNITIVE TRAINING EXAMPLES

1. KREMLIN-BICETRE, PARIS – BRAIN GYM

2. TYPE C – CHAOS CHANGERS OR EXPERT PROBLEM SOLVERS

3. CENTER FOR DECISION RESEARCH, U. OF CHICAGO "THOUGHT TRIALS"

C.1 Brain Gym

In France, neurologist and psychologist Monique Le Poncin-Lafitte has developed a program to improve memory, logic, attention span and organizational ability. She calls her program "Brain Fitness" and has tailored exercises to improve mental agility and diversity of thinking (Le Poncin, 1990). Brain Fitness is given as a month-long course at Kremlin-Bicêtre, a hospital near Paris. Reported successes include:

- 32.5% improvement in mental agility
- 47.3% improvement in visual/spatial memory
- 20.1% improvement in verbal memory

The month of brain exercises is divided into three sessions per week, with each session lasting no more than 15 minutes. The program of exercises is based upon five types of mental activities.

1. Perceptual Activity -- The goal here is to train the sensory memory. Senses of sight, hearing, smell and touch are developed for speed as well as acuteness and discrimination. These exercises prepare the trainees (or pilots) for dealing with time pressured situations or problems which they may have never encountered previously.

2. Visual/Spatial Activity -- The training here deals with both sight and space. Attention, associations, elaborations and expectations are dealt with from an information processing perspective. Situational awareness is heightened by combining the perceptions of location, time, distance, interval and orientation.

3. Structuralization Activity -- The training in this activity teaches the individual the abilities of organization, patterns construction/recognition and forming a coherent whole out of individual elements observed and fitted together. This

47

cognitive training is directly relevant to the recall and reconstruction capabilities so critical to long term memory.

4. Logical Activity -- This training uses arguments, deduction and reasoning to discover the meaning and coherence of specific situations or concepts. Coupling new ideas to old, developing procedural rules and association principles results in superior information processing.

5. Verbal Activity -- These exercises require precise communication to define abstract representations of people, relationships or situations. Visual/verbal, aural/verbal and conceptual activities are included. Understanding and vigilant awareness activities enhance self-monitoring and strategic decision making ability.

C.2 Type C Chaos Changers or Expert Problem Solvers

Both theoretical research in balance theory (specifically cognitive dissonance and consistence) and common psychology agree on one specific problem solving point. People, even pilots, will do everything they can to solve problems and restore a sense of balance, control and order. Some try to wish the problems away. Others deny or ignore the real issues. Many people try inappropriate, negative behaviors hoping to mask what is really going on. Others think that by applying a tried and true solution from the past, will make the current problem go away.

At the Center for Studies in Creativity at Buffalo State College in Buffalo, New York, Dr. Roger Firestein acknowledges that the "hot topic right now is problem solving". Dr. Firestein and his colleagues are researching the characteristics of expert problem solvers. They have documented that the effective problem solver knows how to identify the right problem and implement the right solution at the right time. This has also been termed "knowing when" (Dreyfus and Dreyfus, 1986). That is, the Adaptive Expert Pilot perceives the necessity to alter ingrained procedures based upon the parameters and dynamics (or cues and context) of the problem or situation encountered. It is believed that this "KNOWING WHEN" (an almost direct perception of the proper course of action) may provide the key to the next generation of ADM training.

Dr. Firestein has trained thousands of individuals in effective problem solving using a two phase, six step method. They employ a stepwise problem solving model that uses forward inferencing in the information processing solution. First, is the problem identification phase; second, is the solution generation phase.

1. The first step in the training process is choosing to become involved in the finding of a solution. Firestein calls this "mess finding". He also recognizes it as

intuitive in that the problem may not even be well identified, yet the pilot or problem solver knows that something is wrong and requires attention.

2. Finding all the information possible about a situation is the second step. The Center for Creative studies defines data, which is different from information as including all of the feelings, impressions, thoughts and subjective elements of a situation.

3. The third step in the problem solving training is to identify and prioritize the most important pieces of the situation. In some cases, this involves defining more than a single problem as comprising the current situation.

4. This first step in solution development involves defining as many ideas as possible to respond to the problem. These can be done individually or as part of the a group's response to a problem, e.g., a crew in the case of aviation.

5. Selecting alternative solutions is the next step of the training program. Each alternative should be compared to the probability of success based upon its own potential for solution and ability to resolve concerns.

6. The final step involves acting on the solution. That is developing a stepwise implementation plan to change the situation and solve the problem.

Although this sounds very structured and linear, Firestien has looked at problem solving groups with and without the training in dynamic, unfamiliar situations. He has recorded that the trained groups start solving the problems from their first intuitive perception of something being "not right. That is, the effective problem solving training teaches individuals techniques to produce controlled outcomes, solutions even in chaotic situations.

C.3 Thought Trials

The University of Chicago's Graduate School of Business has a Center for Decision Research. Dr. Robin Hogarth of the Center has been working on the science of decision making and problem solving issues since 1980. One of the most interesting and productive efforts to improve decision related skills has been the use of a series of mental manipulations or "thought trials" to improve association and retention capabilities.

In these exercises, a series of conceptual problems, hypothetical situations or imaginary experiences are presented in a rapid, timed sequence. Individuals are required to try as many solutions as possible, as rapidly as possible and until a satisfactory solution is obtained. Dr. Hogarth's theory is that creative thinking and problem solving involves precisely the same principles as trial-and-error learning

(Hogarth, 1989). The thought trial process is based upon the theory that this "blind variation" or randomness builds the individuals ability to provide foresight in new situations by providing a very large number of associative problem solving paths. Furthermore, the paths which lead to correct solutions are retained as strong connections since the overt behavior of "finding" a solution is accompanied by the feelings of accomplishment and discovery. The "something clicked" or "eureka" experience usually marks the successful termination of the process.

An important implication of this research is that chance plays a crucial role in decision making and creative thinking. Dr. Hogarth doesn't see anything wrong with this. On the contrary, this observation substantiates the fact that expert decision making and problem solving abilities are not "something special" that only a few select individuals have or can acquire. The fact that creative problem solving is not a unique capability has been pointed out by other researchers throughout this report. However, the Center's research goes one step further and recognizes that the individuals can "learn" to be more capable. Four important sources in developing creative problem solving are delineated:

1. People vary in their capability to produce a wide range and large number of thought trials. That is, imagination and motivation to produce thoughts and practice problem solving are skills. An individuals "investment" in thinking increases the probability of being successful in finding solutions.

2. Longer experience and exposure in a field equips people with the capability of better problem solving skills. The wider exposure increases the range of possible thought trials they can produce.

3. Working and training in a field that fosters independent thought and exploratory behavior can liberate the individual mental talents for generating creative solutions.

4. People differ in their ability to seize upon solutions that are appropriate. That is, it is not sufficient to be able to generate a large variety of solutions. The individual must be able to decide which solution should be implemented.

Research using thought trials has shown that all of these individual differences can be learned to varying degrees (Hogarth, 1989). All are extremely important to the expert aviation decision maker. However, the fourth trait is especially appropriate to aviation problem solving. Pilot's must learn to facilitate the "editing" or selection process while retaining the ability for wide scanning of possible solutions.

This wide scanning has also shown to underlay an individuals ability to generate solutions to new situations. Therefore, by engaging in large numbers of thought trials, the creative expert increases his chances of solving new, previously unencountered problems when they occur.

In summary, the thought trial research has shown that the invention of creative solutions depends upon generating many thought experiments or combinations of factors capable of leading to solutions. This practice plus the development of the mechanism to select, test and retain "successful" solutions may be precisely what expert pilot decision making training should provide.

APPENDIX D

EDM TRAINING TOOL EXAMPLES

This section provides three examples of Expert Decision Making tools which can be used for either training decision making skills, evaluating cognitive performance or in one case as a screening tool to determine a priori if a student pilot has good decision making skills. These tools were selected due to their tailored development in the aviation human error reduction field. However, they are not intended to represent the recommended choices or even a prioritized list. Rather, they are to represent the type of interactive tools which can expedite and enhance how pilot's think and solve problems.

D.1 COCKPIT EMERGENCY PROCEDURES EXPERT TRAINER (CEPET)

The CEPET system was introduced in Section 5.3. It is a PC based training program for helicopter pilots which provides self-paced training in cockpit procedures, pilot decision making and emergency procedures. The program has several modules with flight planning, flight scenarios, situational awareness and stress management. The pilot can practice his ability to recognize problems with only partial cues and choose correct solutions as discussed previously in Section 5.3. The following paragraphs provide additional detail on CEPET capabilities.

Other CEPET modules allow the pilot to "fly" a particular scenario which has been associated with an actual accident, incident or bad decision making which can lead to human errors. As pointed out in the Hogarth research, practice with this type of decision making training device increases knowledge and awareness by both providing more associative and elaborative connections in long term memory and by forcing the pilot to "select" a course of action. This interactive device can also be considered to provide a "synthetic experience" which augments actual flight experience or simulator training. Exposure to a large number of problems increases the pilots perception and recognition skills while simultaneously improving judgment and motivation action.

The CEPET type of training is also available on interactive video systems at various flight training schools such as Flight Safety International, Simuflite, etc. These types of training devices are strongly recommended for EDM training since they help widen the pilots exposure to problems, recognize promising approaches, deal with

new or novel failures in a non-life threatening environment and teach the important EDM skill of dealing with incomplete or ambiguous data.

D.2 Wondrous Original Method for Basic Airmanship Testing (WOMBAT)

Historically, flight personnel selection techniques have emphasized skills and basic intelligence. These measures are reasonably good at predicting success early in flying training and certainly pilots or crews without reasonable flying skills and intelligence would not perform well under operational stress. Yet these pilots do not all perform the same as problems develop later in the actual flight situation. Some will be far more successful than others despite their apparent uniformity of skill. In fact, large differences among pilots are discovered as problems develop, situations deteriorate, tension mounts and confusion results from actual operational stress. Research (Roscoe & North, 1980) into the underlying reasons for these differences has shown that there are four basic characteristics which are useful as subjective predictors of this variability in pilot behavior:

1. Attention left over to take care of the emergency while not losing control of the routine operation of the aircraft.

2. Ability to estimate quickly probable outcomes for different courses of action.

3. A sense of relations which allows rapid reordering of priorities as situations deteriorate or improve.

4. Decisiveness of action in the face of indecision by others

WOMBAT is a pilot decision making evaluation and selection tool designed to screen pilots for basic abilities or attributes credited to operationally effective pilots. A microprocessor based system, WOMBAT integrates generic information processing algorithms with new pictorial codes and new decisional paradigms into several interactive subtasks. The thesis behind WOMBAT is that today's pilot is an information manager as much as he is a skilled aviator. Pilots must search for, evaluate, and integrate information not only about the status of the various aircraft subsystems, but also about the multiple other factors associated with flying the aircraft, navigating, communicating, etc. Performing these multiple functions is the essence of airmanship, but the human characteristics which make the whole process possible can be measured by creating complex physical problems involving multiple information channels with pictorial information codes which compete for the pilot's limited pool of attention.

Therefore, throughout the WOMBAT testing, the pilot is presented a set of vertical scale, dual indicators showing the relative weightings of the various tasks including current performance for those "in-play", and available for future and use. The sum of the products of the weights and the performance difficulty on the tasks in-play minus "investments" in information and "penalties" for mistakes gives the pilot an overall indication of his current performance. A "predictor" of total points now and a final ranking based upon extrapolation of current performance for the time remaining allows the pilot to decide whether or not to try different tasks.

Pilot's using WOMBAT are presented primary tasks which include: single-axis left hand "altitude" tracking and dual-axis right hand "flight path" tracking. These primary tasks serve as background workload for all other time-shared problem solving. However, each tracking task has an autopilot mode that can be engaged, at a cost in points, to free the pilot to pursue other methods of earning points. Of course the autopilots are prone to failures that vary from gradual to abrupt. Therefore, these autopilots must be monitored frequently even though the pilot is working on other tasks. In addition, the autopilots are "cheap" in that they provide less accuracy than manual tracking. In this way, the pilot must face the decision to revert to manual tracking when the problem includes high weights to tracking accuracy.

Although the tracking tasks are primary in the sense that they cannot be ignored without significant penalty, the pilot is given "secondary" tasks which provide problems and opportunities for the pilot to demonstrate future airmanship skills. These other sources of activity are of two types. One type provides pieces of information, some immediately useful (such as an autopilot failure classification), some useful in the course of the problem, and some irrelevant. The other type will be the source of side tasks, the performance of which can yield rewards (and penalties) in various forms. Problems can be requested and rejected at no cost or accepted for scoring. Both of these types of activities will have dual-aspect indicators as with the tracking tasks.

In using WOMBAT, the types of behavior which produce high scores include: discovering rules that may not be explicit, through induction and deduction; finding out what is important both at the present and in the long perspective of the situation, and allocating priorities accordingly; perceiving a situation's true characteristics by avoiding subjective biases and being vigilant; recognizing serendipitous opportunities quickly and seizing them before the opportunities pass; remembering to do a specific action at a specified future time; ignoring irrelevant

distractions; and, finally, tolerating frustration when the problem intensifies or the situation is deteriorating.

The task structure outlined places a high premium on rational attention allocation strategy, vigilance, perception, the pilot's ability to assess what is really important, and the ability to remember to do things that are important in a specified sequence. All of these variables have been shown to be critical to the pilot's airmanship. The design of the testing, scoring and tasking is meant to identify those pilots who will fail in an emergency to perceive the true level of risk of the situation, will fail to prioritize tasks correctly, and will ignore opportunities to seize any fleeting choices or decisions to avert disaster.

D.3 Cognitive Effectiveness Markers

The FAA/NASA/University of Texas Crew Performance Project has been developing evaluation criteria for multi-crew decision making and problem solving. In the air line environment, the 1990s have become a period of focusing on crew resource management (CRM). That is, a time when the true team resources are described not only in terms of the cockpit crew but include: the cabin crew, dispatch and maintenance personnel. This team performance has been recognized as a critical part of insuring safe and efficient flight.

Crew Resource Management (CRM) training in this context has been developed by several air carriers. The goal of this training is to improve the effectiveness of these groups themselves and the quality of interactions between them and the cockpit crews. However, with the large time and financial investment required by the airlines to support these programs, it has become critical to develop evaluation and assessment techniques both as a means of tracking the effectiveness of the training and as a means of insuring continuous improvements.

For that reason, the cognitive and interpersonal markers are repeated here as a third example of the types of tools available for EDM training program development and as guidelines.

1. COMMUNICATIONS PROCESS AND DECISION BEHAVIOR SKILLS/ATTITUDES

Briefings/Debriefings
Inquiry/Assertion
Crew Self Critique
Conflict Resolution
Communication
Decision Making

2. TEAM BUILDING AND MAINTENANCE SKILLS/ATTITUDES

Leadership
Concern for Operation
Interpersonal Climate
Group Climate
Automation Management

3. WORKLOAD MANAGEMENT AND SITUATIONAL AWARENESS SKILLS/ATTITUDES

Preparation
Planning
Vigilance
Workload Distribution
Distraction Avoidance.

The actual use of these markers in pilot flight training is still to be determined. However, in the air carrier simulator environment the subject of CRM evaluation comprises an entire report itself and is outside the scope of this project. The reader is referred to the CRM Industry Workshop report (Lofaro, 1992, and the SAE ARD 50037, Adams, Summwalt, et al) for additional specifics on this topic including: philosophy, scenario development, rating criteria, rating forms, etc.

APPENDIX E

EDM TRAINING METHODS

Based on the research from Phase I and II of this project on Expert Decision Making, three promising EDM training/testing methods are suggested as applicable to future pilot training in decision making. These are:

- Metacognition Training (under evaluation using novice pilots at Massey University in New Zealand)
- Intuitive Decision Making Testing (evaluated intuitive decision making skills of over 3000 managers)

These methods have been empirically tested and offer encouraging examples of what can be done. The FAA is encouraged to pursue the application of these methods to pilot expert decision making training.

E.1 Metacognition Training Program

The School of Aviation at Massey University in New Zealand has been developing and evaluating expert decision making training of ab initio pilots since 1990 (Hunt, 1991). Their program was briefly discussed in Section 5.3 additional details are provided in this appendix. The training program at Massey focuses on the Approach to Learning, the pilot Self-Concept and Metacognition. The metacognition training teaches information processing in the learning context, self management of the situation, and memory development all important to EDM.
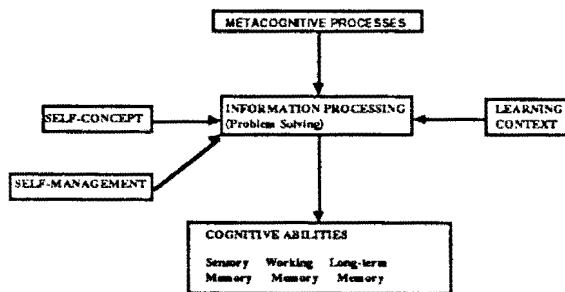
The Massey program was developed as a result of recognizing that human error accident causes have underlying information processing causal factors and that if ab initio and novice pilots can improve the efficiency and effectiveness of their "thinking", and thus improve their monitoring and evaluative or problem solving functions, then, their overall performance as pilot-in-command will improve.

It was with these considerations in mind that an expert decision making course was developed. The course sets seven objectives for the student pilots which are considered to be evidence of improved decision making (Hunt, 1991).

1. Increased self awareness of their own learning processes.
2. A more cognitively active role in classroom learning.

57

3. More control over, and responsibility for their own learning.
4. Greater ability to evaluate and monitor their own learning performance.
5. A strategic use of cognitive (problem solving) strategies.
6. Improved examination performance.
7. A deep, holistic approach to learning rather than a superficial approach.

Influences on Effective Information Processing

Research with the student pilots at Massey University lead to the conclusion that there was a complex interaction between the internal and external factors which influenced a pilot's ability to confront challenging situations. Internal factors included the abilities of students to monitor their own responses to situations (metacognition) as well as to solve the basic problems presented. These situational awareness functions (monitor, control and evaluate) manifest themselves when pilots experience an awareness of the range of possible decisions and are able to select appropriate solutions for a specific problem or task. As they work through a problem, the metacognitive student will regularly check their progress. When a failure in the solution occurs, they identify and resolve it quickly.

The Course

Due to the dilemma of developing a course for the average student while trying to teach expert decision making, it was necessary to develop a compromise between individual attention and group learning. Therefore, the course begins with an overview of information processing and the factors which can influence effective learning. The basic course syllabus provides the students with the appropriate knowledge and procedures to interpret and understand their own "thinking" or decision making processes.

Very early in the course the pilots are introduced to time-pressured and dynamic decision situations. They are required to identify actions, set priorities and apportion their time to specific tasks. They are encouraged to continually review and evaluate their decisions. The following rating factors are used in the evaluation of the student pilot performance. First, they are rated on their ability to analyze objectives and evaluate the content of the task or situation. Analyzing objectives

APPROACH TO LEARNING	SELF-CONCEPT	METACOGNITION
Surface Motive Surface Strategy Deep Motive Deep Strategy Achieving Motive Achieving Strategy	Perception of peer attitudes Perception of authority-figure attitudes Assertiveness Personal attitudes Degree of Structure Perception of own ability Anxiety level Motivation View toward hard work	Organization Awareness & use of strategies Evaluating Monitoring

PROCESSING LEVEL					STRATEGY CLASS
USE					PROCEDURALIZE
REMEMBER PARAPHRASE					ANCHOR & COMPREHEND
REMEMBER VERBATIM					MNEMONICS
CONTENT TYPES	FACTS	CONCEPTS	RULES	PROCEDURES	

according to Content Types and Processing Level provides the basis for deciding which cognitive strategies to use and the basis for evaluating the completeness of the information about the problem or situation.

Second, they are evaluated on the appropriate application of conceptual knowledge (facts) or procedural knowledge (rules) used to address the situation. Identifying content types triggers the student to the importance of the available structures and further expands his association of elements of the problem. This also provides a check to the student that all available structural components are used as resources. **Third**, they are evaluated on the remembering and retention phase. For each objective identifying the required processing level helps the student to choose the appropriate cognitive strategies for learning.

On a processing level basis, the lowest level of learning is "remembering verbatim". This simply requires the student to be able to reproduce information exactly as it was presented. This kind of remembering task yields best to mnemonics strategies such as acronyms, chunking and sequential identification. Learning tasks that require deeper processing rely on the meaningfulness of the information. Massey calls these "remember paraphrase" and "use". This type of learning to requires the students to "comprehend" or make sense out of the information in a manner that they can express in their own words. It also requires understanding relationships between facts, objects, results, as they occur in context. This is accomplished through elaborations and associations which stimulate prior knowledge and establish the necessary connections between existing structures and new material.

Once information is taken in, understood and structured for use, it must be "anchored" in memory for ease of retrieval. Current literature on expertise recognizes the ability to use and apply knowledge in "real situations" is as much dependent on easy retrieval as it is of organization and storage. The Massey course teaches two strategies for anchoring knowledge: Associating, i.e., creating analogies which elaborate on the knowledge base; and, Generating, i.e., practicing applying the information to new situations. Both techniques are used to force the students to go further than just resolving the current situation. These traits are based upon the observation that expertise comes through the use of knowledge and not just by the availability of facts.

Metacognition or Super Situational Awareness

In addition to teaching expert decision making, Massey students are taught to be aware of their own problem solving abilities. They are taught to assess how well or how poorly they are performing and can take alternative actions to improve their performance. These self-monitoring activities are another typical characteristic observed for experts in other fields. The cognitive psychology field refers to this activity as metacognition. In aviation terms, the monitoring and continual evaluation of the viability of a flight is referred to as situational awareness. Insofar as the Massey students exceed the normal monitoring of flight progress and the situation and actually monitor their own decision making and problem solving this could be called Super Situational Awareness.

At Massey, raising student pilots awareness of their metacognitive functioning begins when they are given their **learning profiles** at the start of the course. The students are each asked to evaluate the "truth" of these profiles and reflect on their own learning processes. This awareness is continued by the students in a journal or diary in which they keep records of their learning experiences, successful decisions, problematic outcomes, thoughts, feelings and insights. These structured, written exercises discipline the pilots into a regime of planning, analyzing and monitoring their own cognitive performance. This exercise also provides the students with support for developing metacognitive skills before they have been able to completely automate or internalize these strategies.

Summary

The pilot who is able to recognize that a particular decision or problem solving strategy isn't working and can select another strategy from a repertoire will complete the task more quickly and completely that one who does not identify this deficiency in cognitive processing and is therefore unable to take remedial action. Since a critical ingredient in decision making is access to relevant information, the Massey training seems headed in the direction of providing the required expansion in knowledge base and ease of retrieval in addition to the enhancement in self-monitoring. Without appropriate knowledge, pilots cannot make good decisions.

E.2 Intuitive Decision Making Testing

A successful field testing of intuitive decision making skills of over 3000 managers was performed throughout the U. S. in a wide variety of organizational settings in the 1980s. These settings included business, government, education, military and health and a wide range of management levels. This experience and the positive results suggest a cost-effective opportunity to transfer developments in appropriate testing or training from the management field to aviation. The following details are provided as an expansion of the summary description previously introduced in Section 5.4.

Field Testing

The groups tested included a wide range of different organizations and settings including private sector chief executive officers, emergency preparedness military personnel, community college presidents, state health and rehabilitative services managers, city managers, state legislators and staff, professional civil servants, and executives across the country. Over the series of tests, two different but complimentary test instruments were used. The instrument used to measure underlying intuitive ability consisted of twelve questions selected from the Myers-Briggs Type Indicator (MBTI), a psychological instrument that, among other things measures a person's ability to use intuition, as contrasted to deductive reasoning, to make decisions (Myers, 1987). This instrument was selected for use because it has been widely applied in practical settings across the country, and has been proven to have a high degree of reliability and validity as a test instrument. A scale was constructed for this part of the test so that each manager could be ranked exactly from top to bottom on how they scored individually, and also how they compared to other managers taking the test. The maximum score was 12 (highly intuitive) with a minimum score of 0 (little or no intuitive ability apparent).

The second instrument measured whether the managers tested actually used their intuitive ability to make important decisions, and if so, how. These questions were designed for follow-up testing based on the pattern of responses received af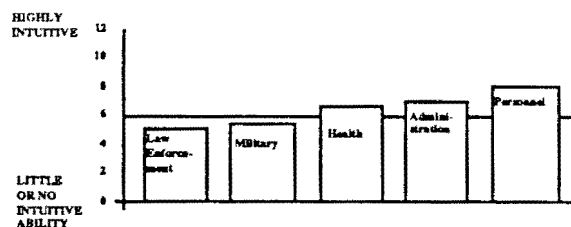ter administering the first test. The test was also designed to obtain data on a number of related questions such as whether executives who used intuition to guide their decisions actually shared

INTUITIVE MANAGEMENT TESTING TECHNIQUES			
PART	SOURCE	PURPOSE	POSSIBLE STYLES
I	12 questions from MBTI	Measures underlying potential ability	INTUITIVE (I) THINKING (T)
II	10 questions self-designed	Measures actual use of ability in decision making	USE (U) NOT USE (NU) OPEN (O) CLOSED (C)
TOTAL	AIM Survey (Agor Intuitive Management)	Measures both potential and actual use of intuition	I-U, O I-U, C I-NU, C

this fact openly with their colleagues or kept it a secret. When used together, these two tests became powerful tools for measuring a manager's intuitive decision making ability. They may offer interesting parallels suitable for use throughout aviation.

AIM Results

Responses were stratified for such key variables as level of management, level of government, sex, occupational specialization, and ethnic background. All of the responses were analyzed by computer and all the findings were subject to statistical significance tests. The findings from this national testing dramatically indicated that intuitive management ability appears to vary by management level, by level of government service, by sex, by occupational specialty and, to some degree, by ethnic background (Agor, 1986). Intuition appears to be a skill that is more prevalent as one moves up the management (experience) ladder. Sample results are shown on the left.

Top managers in every sample group tested scored higher than middle/lower level managers in their underlying ability to use intuition to make decisions. It also appears that the higher one goes in the level of government service (from county to national), the greater the ability to use intuition becomes. Finally, it appears that top managers rely most frequently on their intuition since they are constantly called upon to make choices in turbulent environments where problems do not lend themselves to serial, deductive or probabilistic reasoning.

Because of these strong parallels, and the documented, national findings across a wide range of fields that the AIM approach to testing is reasonable, a similar approach suitable for testing the pilot memory, information processing and problem solving skills identified as important to EDM was proposed in Section 5.4. As with the AIM, the proposed self-assessment test will be composed of two parts. Each part will contain 12 questions or problems which will be administered as independent self-assessment tests at two different time periods to reduce the immediate influence of Part I on Part II. The self-test will provide each pilot with a rating matrix and personnel decision making style profile similar to the "Hazardous Attitude" profile used successfully in the basic ADM training. Part I will be MBTI based and determine the pilots ability to use, and tendency to prefer, intuitive decision

making. Part II will be cognitive skill based and will evaluate pilots mental attributes which contribute to his <u>actual use</u> of various cognitive styles for decision making and problem solving, up to and including intuition.

APPENDIX F

EDM TRAINING ASSESSMENT

Experienced pilots can be viewed as experts on how to safely fly aircraft and how to safely deal with the full range of emergency situations that can occur while flying. The design of testing methods for this type of expertise has two goals. First, the test should be an assessment of a given pilot's ability to cope with emergency situations and provide descriptive feedback on a given pilot's mental processes during this type of decision making and problem solving. Second, taking the test should be a valuable learning experience and the test should provide explicit feedback on the information that needs to be considered for the presented situation and detailed discussion on different strategies to deal with that situation.

In addition, in comparing the thoughts generated by the pilots who are taking the test to the detailed feedback about different strategies from the second goal, the pilots should be stimulated to consider why they didn't consider various options or selected sub optimal strategies. Tests designed in this manner would provide an essential training tool to attain continued training and enhancement in pilot decision making whereas emergency situations are infrequently encountered in real life. The basic design of the type of tests required for developing adaptive and intuitive expert pilot decision making draws heavily on the material previously presented throughout this report. However, for clarity and ease of reference, the next section will briefly outline the general insights regarding EDM and IDM processes and findings relevant to the assessment of testing and training methods.

F.1 Methodology

The central problem in studying expert decision making in aviation is common to all research on expertise in that the process to be studied occurs in complex and highly interactive situations. Medical experts diagnosing the disease of a patient engage in extended interviews, medical tests and physical exams. Expert athletes are exposed to dynamically changing situations throughout their competitive games. Similarly, pilots are exposed to continuously changing environments in which their responses and actions will interactively change the situation at hand. Hence, a given expert will most likely never encounter the identical situation twice in a life time, nor will two experts ever encounter the identical situation or problem environment. This constraint of not being able to observe many experts (as well as novices) in the same situation is a major challenge for research on pilot expertise.

The general solution to this problem is to analyze carefully the real life expertise to identify brief segments of the expert's behavior that corresponds to a natural occurring task. This type of job task analysis was suggested as the next significant step in the development of decision making training by the participants at the May

1992 workshop (Adams, & Adams, 1992). An example of the type of cognitive task analysis (CTA) was presented by Kevin Smith from United Airlines. His detailed task analysis of taking off with and engine failure at V1 provided 12 decision points which required a specific response. By examining each decision point, it is possible to record the expert decision vs. the novice decision based upon a consensus of high time, accident free pilots. This situation or decision task could then be presented in isolation to a large number of other pilots and ask them to select the best possible solution.
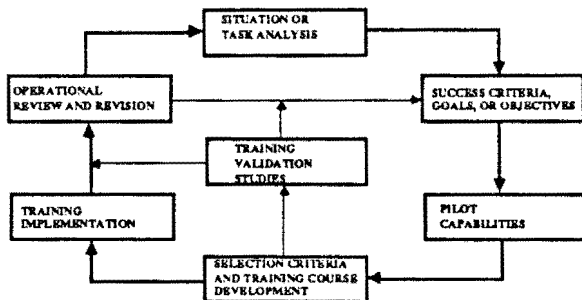
In many task analyses it is possible to explicate a limited number of sequences of thoughts that will adequately describe how subjects generate the best answer or some alternative answer for a given task. These alternative thought sequences make it feasible not only to describe other subjects' efforts to complete the task, but would provide the potential of giving feedback to subjects generating sub-optimal answers/actions. Analyses of expert performance using this type of task analysis has revealed a perspective of general characteristics of experts' cognitive processes.

F.2 Desired Characteristics of EDM Processes

Based on the research on expert decision making from Sections 4.0 and Appendix A, a consistent picture of the organization of expert knowledge and problem solving has emerged across a wide range of fields. In a task analysis of a medical diagnosis, for example, all possible diagnoses can be sequentially checked to see if they can be ruled out. If only a single possible diagnosis remains, the diagnosis is complete. This is a useful method to analyze the task and how presented information can be used along with other knowledge to eliminate alternative diagnosis. However, human medical experts do not proceed in this fashion. The medical expert sequentially integrates the presented information and will only explicitly consider a very small set of reasonable diagnosis. In dynamically changing environments, like aviation, the expert maintains an updated representation of the current situation or in medicine, the proper diagnosis.

For the type of tasks presented to pilots, from setting up a procedure turn for an instrument approach to dealing with engine failures, the first step in expert performance is to rapidly encode the presented information to generate an integrated representation of all relevant information about the current situation or task. Once this integration is complete, the expert virtually automatically retrieves a small number of appropriate actions/solutions. **This retrieval is not a deliberate search for alternatives, but the retrieved potential actions simply occur to the expert due to a direct recall based upon elaborate internal knowledge representations.** Subjectively, this direct retrieval process is perceived as intuition. At this first phase

65

the expert has no assurance that these actions are the best nor that they completely reflect all relevant constraints of the situation. It is during the following second phase that these retrieval alternatives are carefully evaluated and in some cases rejected in favor of better alternatives.

For highly familiar situations previous experience and earlier corrected mistakes essentially assure that appropriate and correct actions are retried. However, for unfamiliar situations the retrieved actions can be viewed as heuristics and thus are not necessarily best or even entirely appropriate. Research of expert's decisions in other fields has shown that their intuitive ideas are good, but that quite often (30-50%) of the time, they are rejected after a more careful evaluation of the possible alternatives for the situation presented (de Groot, 1978).

A large body of research has studied the integrated representation of situations encoded by experts in expanded memory. Novices and lesser experts are simply unable to internally represent the presented information and memory studies show that these subjects can only recall a fraction of the presented information after brief 5 second exposures. In contrast, experts can virtually recall all relevant information perfectly. The experts' integrated representation of the current situation plays a critical role in the experts' more systematic evaluation of alternatives during the second evaluative phase. The expert can plan out consequences of various actions and internally represent and evaluate these future states.

The amount of time available for this second phase of systematic evaluation differs from situation to situation and from time to time in the same situation. There are several methods to anticipate issues and perform necessary evaluation that will allow an expert under real-time constraints to reduce the necessary processing at the point of making the decision.

1. Planning and preparation of alternatives before the situation or procedure is required in real flight situations.

2. Concurrent updating and evaluating of information at the first possible opportunity.

In virtually all areas of expertise, the most effective learning takes place after the event, when the course of events can be carefully evaluated without any real-time constraints. Analyzing videotapes of LOFT simulator sessions is a good example. Most of the actual learning and further improvement of the expert performance is due to training inspired by such post-event analyses. In addition, descriptions and recordings of other pilot's and crew's performance can similarly be used as opportunities for learning. Accident/incident videotape re-enactments are an example here.

F.3 Implications for EDM pilot testing/training

The preceding discussion of research results, principles of experts and characteristics of expert problem solving produce a general format for the desired pilot testing of expert decision making. The tests should be composed of a series of items. Each item has three major parts and some variations.

PART I: A detailed description of a flight situation (or pre-flight) • a picture of the instrument panel with appropriate situation readings • a picture of external weather, traffic, runway configuration, etc.	PART Ia: On the following page a list of questions testing whether the pilot can recall most of the relevant information presented on the first page	TEST FOR GENERATED INTEGRATED REPRESENTATION OF THE CURRENT SITUATION
PART II: On a separate page present a description of a critical event and a request for a decision about relevant actions	PART IIa: As an optional exercise, present (on a separate page) a listing of 3-5 possible courses of action and a request to select one of them as the one closest to their spontaneous answer	TEST FOR HOW MUCH TIME IS REQUIRED USING A STOPWATCH OR AN EGG CLOCK RINGING AT SOME PRESET TIME
PART III: Present an expert analysis of the situation outlining possible courses of action and discussion of the possible consequences associated with each choice	PART IIIa: As an alternative to PART III, present the "best" course of action (or best courses when two are equally acceptable). Discuss sub-optimal or incorrect actions sequentially providing detailed discussion of their unfavorable consequences and plausible reasons for their selection	TEST FOR DISREGARD OR NEGLECT OF CRITICAL PIECES OF PRESENTED INFORMATION UNDER PART I

The following considerations are critical to the scenario generation:

1. Selecting scenarios with realistic situations and critical events.

2. Adapting scenarios to make a task analysis with a small number of reasonable sequences of actions possible.

3. Evaluation of test performance and self-evaluation of employed decision making processes.

F.4 Selecting Realistic Scenarios with Critical Events

It would be preferable to elicit real-life events from experienced pilots and then try to adapt them to the recommended three-part format. Being able to present the encountered scenarios as events from real experiences will improve the face validity of the test. This development should also strive for scenarios and critical events that require similar actions for large classes of airplanes or could be easily adapted to a specific airplane type.

Another source of scenarios and critical events can be abstracted from simulator training programs, which are no longer in use. A final source would be to seek out clear critical events and then adapt them with a typical scenario. At least some small portion of the problems should be very different involving combinations of error (a hidden error in the current situation plus a critical event). The pilots should be told about the range of possibilities prior to the start of taking of the test.

F.5 Adaptation of Scenarios: Task Analysis

The real-life scenarios will require substantial adaptation to yield a small number of plausible courses of action. Potential courses of action can be eliminated by adding information in the scenario (PART I). Simple courses of action can be made more difficult by manipulating sets (e.g., information about an earlier problem with the hydraulics system) and inclusion of other irrelevant information on PART I.

Another less theoretical approach is to plan a relatively large field testing with scenarios without explicitly given options and then categorize the volunteered options into groups that can be restated as actual options for the real test. As a result of this field testing, information can be added and taken away to adjust the difficulty of each item.

During this phase it is essential to have access to a group of super-expert pilots to assure realism and to write the feedback portion (PART III and PART IIIa).

F.6 Test Performance and Self-Evaluation of the Decision Making Processes

Using the proposed design of items with a fixed set of alternatives and only one or two alternatives being the best, scoring of the test should be straightforward. It may also be possible to categorize sub-optimal or incorrect alternatives in different categories such as:

      a. forgot or neglected facts given in the situation (PART I)
      b. Violated FARs or Company procedures (SOPs)
      c. Insufficient knowledge about the aircraft, systems, procedures, etc.
      d. Willingness to accept a higher than necessary risk

68

It may be difficult to construct alternatives that uniquely reflect one of these error sources, so the pilot may have to check off one or more of these when confronted with the feedback in PART IIIa. These errors could then be summed to provide an expertise profile.

There are a number of possibilities for more detailed self assessments once a preliminary version of the test is developed. At that point, a sample test of pilots should be given a "think-aloud" type of test and retrospective reports on their thought processes recorded. From these sample decision making "records" there are other possible directions that the testing/training could proceed:

1. Assessment of the pilots' memory for the presented information in PART I after a standardized exposure time evaluating the following:

    a. Recall
    b. Test of meaningful integration
    c. Test for ability to generate likely problems or incidents given a presented current situation (Comprehension and Inference)
    d. Questions about what kind of preparation that should have been already done for a flight like the one described in PART I (Comprehension and Interference)

2. Assessment of the pilots' ability to respond rapidly and access intuitive courses of action. By varying the time to come up with an option from 2-5 seconds (including the reading of the situation description and/or the critical incident) to 30-45 seconds, one should be able to vary the reliance on pure intuition and intuition with subsequent systematic evaluation. It is possible that pilots differ and that some always are satisfied with intuition, i.e., no systematic evaluation even with long times, others may simply be unable to rapidly respond and require generation of alternatives, which will incorporate some degree of evaluation. Roughly four groups could be postulated as shown on the left.

EDM ASSESSMENT GROUP

COGNITIVE	ASSOCIATIVE
AUTONOMOUS	INTUITIVE

Further detailed development of scenarios and discussion of self-validation will require feedback from the readers of this report, the critical review of the FAA Technical Monitor, other appropriate FAA personnel and others pilots with varying amounts of experience.